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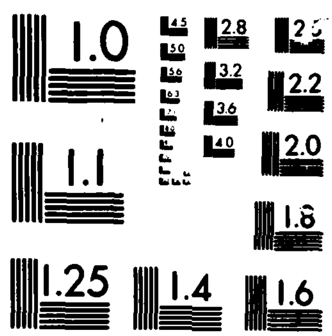

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OCEAN THERMAL CONVERSION (OTEC) PROJECT
BOTTOM CABLE PROTECTION STUDY

ENVIRONMENTAL CHARACTERISTICS
AND
HAZARDS ANALYSIS

C. CHERN & W. TUDOR

OCTOBER 1981

FPO-1-81-(22)

OCEAN ENGINEERING AND CONSTRUCTION PROJECT OFFICE
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covering (a) natural factors of location, tide and currents, wind and wave, bottom soil type and seafloor movement and (b) man-made factors such as ship traffic, fishing activities, ocean mining, government regulations.

These characteristics were studied to determine the hazards which potentially are a source of damage to a cable system. Hazards are as follows: chafe and corrosion , hydrodynamic forces due to wave and current action, mudslides, earthquakes, trawler and/or dredge action and ship anchors.

An analysis of the history of submarine cable failures was conducted.

Executive Summary

This is a study of seafloor cable protection criteria and technology as applied to the four proposed OTEC plant sites and cable routes at Hawaii, Puerto Rico, Guam and Florida.

It includes a study of environmental characteristics for each site cover~~ing~~d: (a) natural factors of location, tide and currents, wind and wave, bottom soil type and seafloor movement; and (b) man-made factors such as ship traffic, fishing activities, ocean mining, government regulations.

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An analysis of the history of submarine cable failures was conducted. Included are the probabilities of damage related to water depth. Probabilities become minimal for all hazards in water depths of 1,500 feet and more. Chafe and corrosion had the highest probability of causing damage to a seafloor cable compared to the other hazards.

Because of the hazards present at all sites, cable burial is recommended as the best means of protection.

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CHAPTER 1. INTRODUCTION

1.1 Background

The Ocean Thermal Energy Conversion (OTEC) project* is a long term program for the development of a renewable, non-polluting source of base load power, essentially independent of season or time of day. Four sites are being contemplated ranging from a few nautical miles to some hundred plus nautical miles off-shore with water depths to 5,000 feet. In most instances the power generated at the offshore OTEC plant will be transmitted to an existing shore-based utility grid by means of submarine cables. The reliability of these submarine cables over the life of the plant must be assured in order to meet OTEC goals. They must be protected for a period of 30 years against both natural phenomena; such as wind storm generated wave action, bottom currents, bottom mudslides, or seismic activity; as well as human activity, such as trawling, ocean mining, anchor dragging of sabotage.

An Interagency Agreement (IA) was initiated between the Department of Energy (DOE) and the U.S. Department of the Navy in July, 1980. The purposes of the IA are to assess the need for protection of the proposed OTEC power transmission cables, identify the means or development requirements for accomplishing the required protection, and determine the costs and benefits associated with this protection.

* - The passage of P.L. 96-310, the Ocean Thermal Energy Conversion (OTEC) Research, Development and Demonstration Act, and P.L. 320, the Ocean Thermal Energy Conversion Act of 1980, formally declared the Federal policy for the development and commercialization of OTEC technology. Collectively, this legislation in part mandates the demonstration of 100 MW of OTEC power by 1986, and establishes as a national goal 10,000 MW of OTEC power on-line by 1999. During the year 1980, a group of three industrial companies and the State of Hawaii launched a tiny plant (Mini-OTEC) that succeeded in generating net power from ocean thermoclines for the first time. Its 12 kilowatts were a symbolic milestone, but it solved none of the engineering problems that face builders of large plants comtemplated under this study.

The Ocean Engineering and Construction Project Office, Chesapeake Division of the Naval Facilities Engineering Command (CHESNAVFACENGCOM/FPO-1) in conjunction with the Civil Engineering Laboratory (CEL) was designated to perform the study of the OTEC transmission cable protection criteria and technology. The main task for FPO-1 was to establish the submarine cable protection criteria requirements; through a study of environmental characteristics, hazard analysis and protection techniques analysis, CEL was to identify contempory cable protection technology.

1.2 OBJECTIVES

The FPO-1 study was to assess the need for protection of the seafloor OTEC power transmission cables along the entire route from the shoreline to the riser cable at each of the four primary plant sites. This assessment will serve as the input to the concurrent study of the cable protection technology conducted by CEL.

The end product of these studies, by both FPO-1 and CEL, will be a Cable Protection Implementation Plan. This Plan, prepared with the assistance and guidance of the DOE, will serve as a roadmap for accomplishing the appropriate degree of cable protection consistent with OTEC requirements and schedule.

1.3 SCOPES

The scopes of this study were to:

- Conduct a literature survey on the environmental characteristics of the specified OTEC plant sites and associated cable routes. The survey includes the natural phenomena and man-made factors which will affect the design life of the OTEC program;

- Perform the historical data search on submarine cable faults. The efforts were to concentrate on the identification, collation, and analysis of existing data regarding cable hazards and faults and their relationship to the OTEC program.

CHAPTER 2. OTEC PLANT SITE AND CABLE ROUTES: LOCATION, ENVIRONMENT & SEABED DESCRIPTION

2.1 INTRODUCTION

This chapter is concerned with describing the environmental and seabed factors affecting submarine cable protection requirements at four specific plant sites. The sites were somewhat arbitrarily selected by DOE and were chosen mainly to represent the rather diverse seafloor conditions expected in the OTEC program. Three of the four sites are "island sites", namely, immediately offshore of: (1) Oahu, Hawaii; (2) Punta Yeguas, Puerto Rico; and (3) Cabras Island, Guam. The fourth site is in the Gulf of Mexico, due west of Tampa, Florida.

Reference 32 resulted from a literature search on the environmental characteristics of the four plant sites and associated cable routes. The following sections are excerpts from this study.

2.2 KAHE POINT, OAHU, HAWAII

Figure 2.1 shows the general location of the potential OTEC plant site and the associated cable route. Coordinates for the plant site are 21°19.5'N, 158°12.5'W. Water depth at the plant site is approximately 3,500 feet and the plant site is about 4.6 nautical miles from shore.

The plant site lies 0.07 nautical miles from the Oahu Submarine Tie Cable which will have to be crossed by the OTEC cable. There are additionally several other submarine cables outshore of the site. The site lies close to Submerged Submarine Operating Areas; these areas normally are 3.0 to 5.0 nautical miles from shore. Pearl Harbor is 15 to 18 nautical miles from the site and cable route and no pipelines are indicated in the area. The landfall is near the Kahe Point Power generating plant, and the shore line is indicated to be rocky. There are no major river flows nearby.

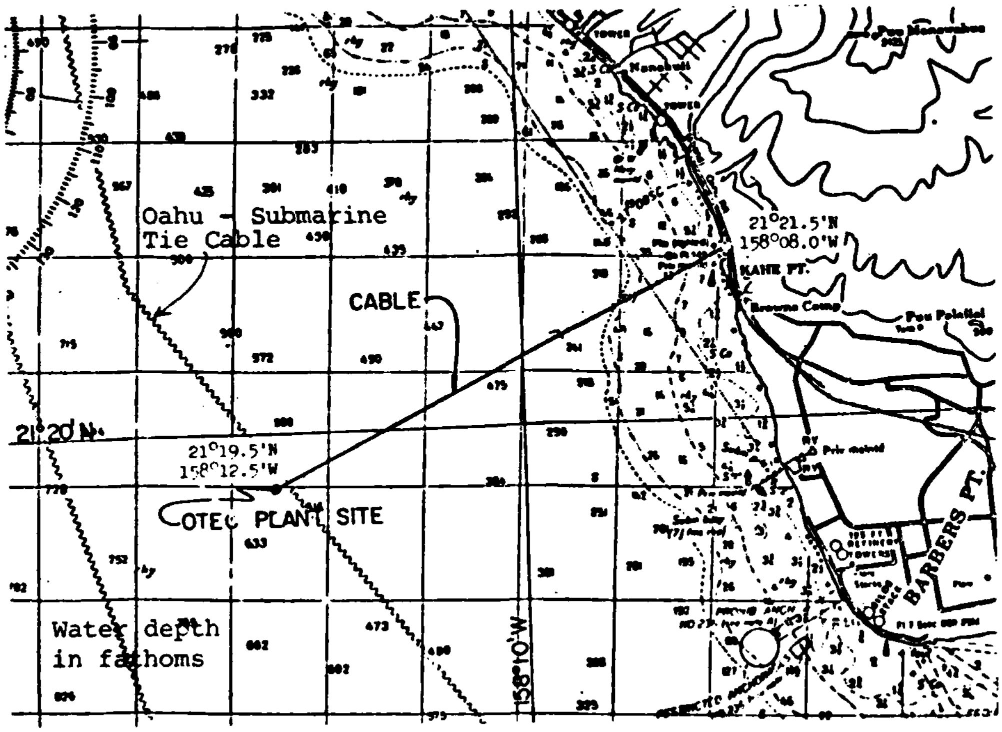


Figure 2.1 Potential OTEC Plant Site and Route

Kahe Point, Oahu, Hawaii

The profile over the seafloor along the cable route is shown in Fig. 2.2 The scale is true, namely, one vertical to one horizontal. The profile shows a flat slope outshore from land for about 1.0 nautical mile at which point the slope is sharply increased to 1 vertical to 4 horizontal until about 3.0 nautical miles offshore. The sea bottom from thereon is again a fairly flat slope to the plant site, where the slope is 1 vertical to 20 horizontal.

Normal tide at this site is semi-diurnal but has considerable inequality in the heights of high and low waters. The range varies from 0.5 foot to 2.5 feet in height. Tidal currents from such a tide over the site are of minimum significance amounting to a maximum of 1.0 knot.

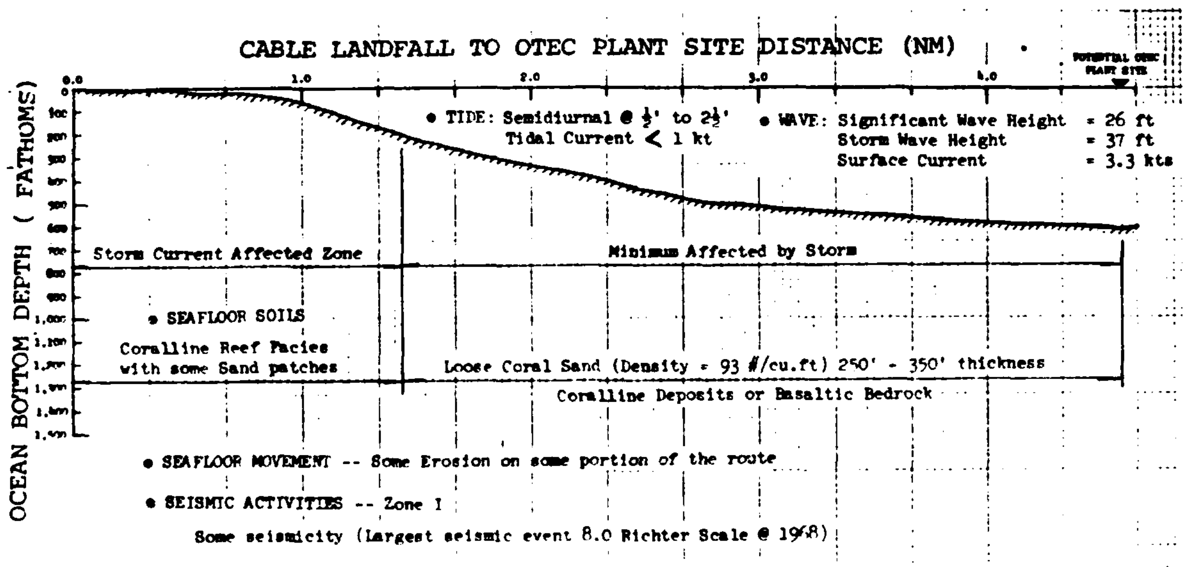


Figure 2.2 Environmental Characteristics - Natural Factors

Kahe Point, Oahu, Hawaii

The proposed plant site is located on the lee side of the island of Oahu and consequently is sheltered from strong tradewinds and high rainfall (about 20 inches per year). Hurricanes rarely strike the islands directly (about 1 in 4 years), but numerous hurricanes and less intense tropical cyclones, most of them drifting westward from formation areas off the Mexican Coast, have approached near enough for their outlaying winds, clouds and rain to effect the islands. Maximum observed and reported winds are about 48 knots.

The sea bottom is expected to be coralline reef material overlain in some cases by deeper water sand deposits. Offshore of Oahu, numerous submerged shorelines and shelves have been observed. Two of these, the Lualualei Shelf (-1,200 ft to -1,800 ft) and the Waho Shelf (-3,000 ft to -3,500 ft) appear to occur in the site vicinity. Water depths increase gradually to about -600 feet, where a relatively steep scarp, the Lualualei Shelf, is encountered

which extends down to about -1,500 feet about 1.0 nautical mile offshore. This shelf is about 1.0 nautical mile wide. A moderate slope extends seaward down to the Waho Shelf at about -3,000 feet, roughly 3.5 nautical miles offshore. This shelf extends beyond the site area. For the Lualualei Shelf, sediment thickness of 250 feet to 350 feet have been reported and similar thickness are likely on the Waho Shelf.

In the near-shore area the sea bottom conditions are anticipated to be coralline reef facies (relatively dense, locally cemented) with some sand patches. With increasing depth, the coralline deposits (or basaltic bedrock) may be overlain by sediments up to a few hundred feet thick. These sediments are relatively loose near the sediment/water interface. Scarps, where present are anticipated to be cemented coralline material. Sediment densities in the vicinity of 1.5 grams per cubic centimeter are found in ocean sediments.

Significant wave heights are given as 26 feet annually and a maximum of 37 feet during hurricane storms. These have been computed for the plant site and are deep water waves. The lengths of these waves (crest to crest) are about 470 feet and 670 feet respectively and water depth at the site is 5 to 7 times the wave length. It can be expected that these waves will move towards shore until they reach the area where water depth is about 1/2 the length of waves (i.e., 230 feet to 335 feet deep). This is about 1.0 nautical mile from shore where the bottom begins its steeper slope. At this point, the waves would tend to break, reform to a lesser height and break a second time as they approach shore.

The maximum resultant current velocity from storms can be expected to reach 3.3 knots in deep water; inshore in the shallow waters where breakers will occur, it can be expected that this velocity may be exceeded. At the plant site and for the outer 3.0 nautical miles of the cable route the current

would be negligible. Sufficient seabottom current to disturb soil particles on the seabottom can then be expected from shore outward about 1.5 nautical miles.

The seabottom for the first nautical mile from shore is expected to be hard (coralline reef facies with sand patches) so that a minimum of soil movement can be anticipated. From the 1.0 nautical mile point outshore the seabottom is expected to consist of gradually deepening sediments so that considerable bottom movement can be anticipated for the next half nautical mile approximately. Seabottom slides are not expected on the slope beyond 1.5 nautical mile since the slope is approximately 1 to 4.

Although the region of the island of Oahu is not characterized as an area of large seismic events, significant seismicity of a less extreme nature does occur. The recent studies dealing with seismic risk evaluations have examined this question primarily with emphasis on the urban areas of land. The largest seismic event in historic times occurred in 1968 in the vicinity of South Point, Hawaii. This earthquake has been estimated to have had an intensity of 8.0 on the Richter Scale and generated a large tsunami.

Tsunamis generated by seismic activity along the Pacific Ocean margin, the circum - Pacific Belt, have also caused damage in the islands. Eight tsunamis have caused damage in the islands since 1820. However, the bottom in the vicinity of the site slopes uniformly seaward and does not present the type of bathymetry which might enhance tsunami buildup.

The man-make environmental factors affecting the potential OTEC plant site and sea bottom cable route are shown in Fig. 2.3. Ship traffic transiting this site is estimated to be 600 to 650 ocean vessels per year. This estimate is based upon written reports reviewed and upon discussion with the operations office at the Port of Honolulu. It is likely that small vessel

traffic and some military sea traffic is not considered in this estimate. Local traffic is more likely to pass just west of the area than to cross through the zone.

There are about 500 fishing boats using the waters off Oahu, mostly for bottom fishing; they include private sport fisherman, charter fishing boats and commercial boats. The average boat is small, about 20 feet in length. Some of the commercial vessels are equipmed with power pulling equipment for water depths up to 1,000 feet. There is under construction a vessel of a length of 67 feet designed for tuna and albacore fishing.

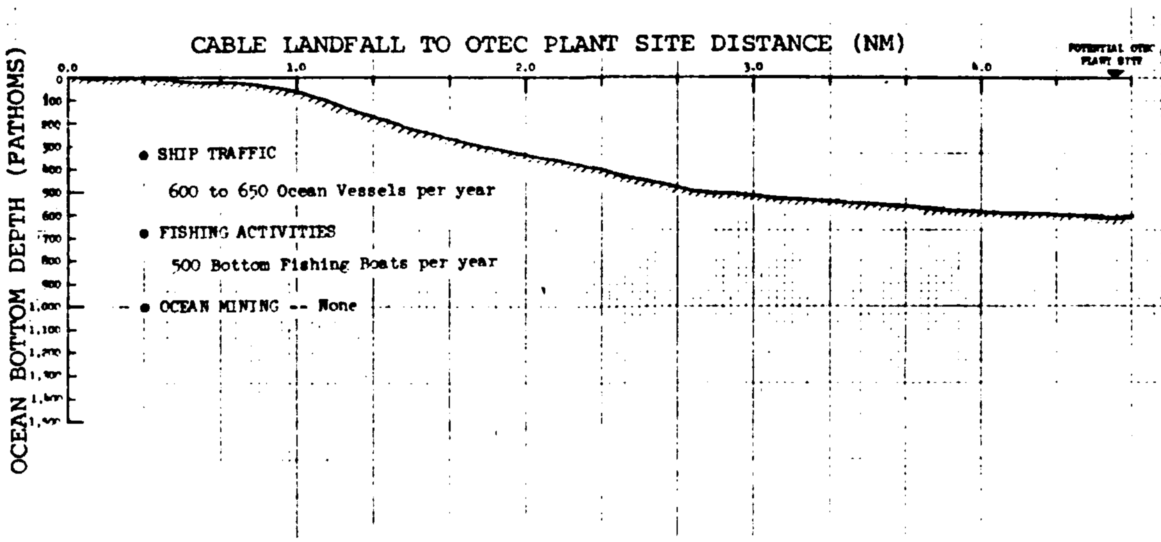


Figure 2.3 Environmental Characteristics - Man-made Factors

Kahe Point, Oahu, Hawaii

The middle Pacific Ocean has one of the richest and densest manganese nodule deposit areas in the world. The manganese nodules are usually present in deep ocean trenches rather than continental shelf rises, areas with post volcanic history, and mid-ocean ridges. These conditions all point to the presence of manganese nodules in the Hawaiian Island waters, including the Kahe Point area. Field investigation has to be done to determine exactly how far offshore the nodules are present.

2.3 PUNTA YEGUAS, PUERTO RICO

Figure 2.4 shows the general location of the potential OTEC plant site

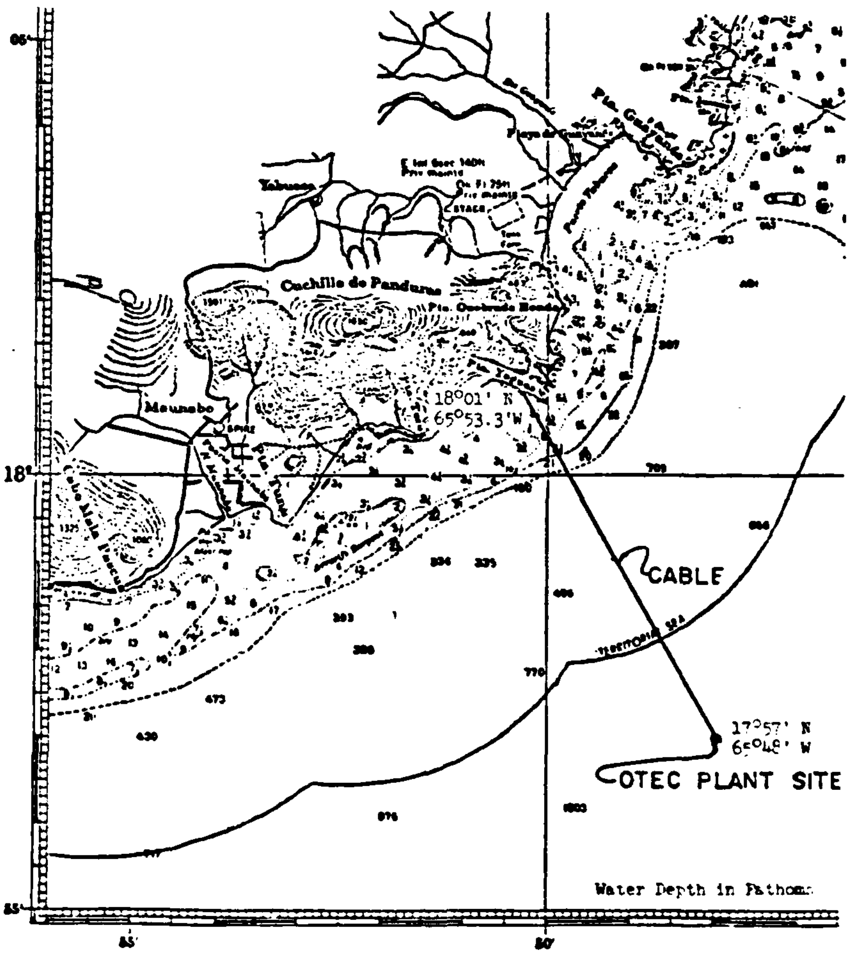


Figure 2.4 Potential OTEC Plant Site and Route

Punta Yeguas, Puerto Rico

and the associated cable route. Coordinates for the plant site are 17°57'N, 65°48'W and for the cable landfall are 18°01'N, 65°50.3'W. Water depth at the plant site is 4,920 feet and the plant is about 4.4 nautical miles from shore.

The plant site lies 1.5 nautical miles beyond the Territorial Sea Line. The site is in line with sea traffic coming and going through Viegues Passage but not in line with normal sea lanes of traffic between the Atlantic Ocean and Panama, Colombia and Venezuela. The site and cable route lies close to Puerto Yabusoa and to Puerto Maunabo. No submerged cables or pipelines are indicated.

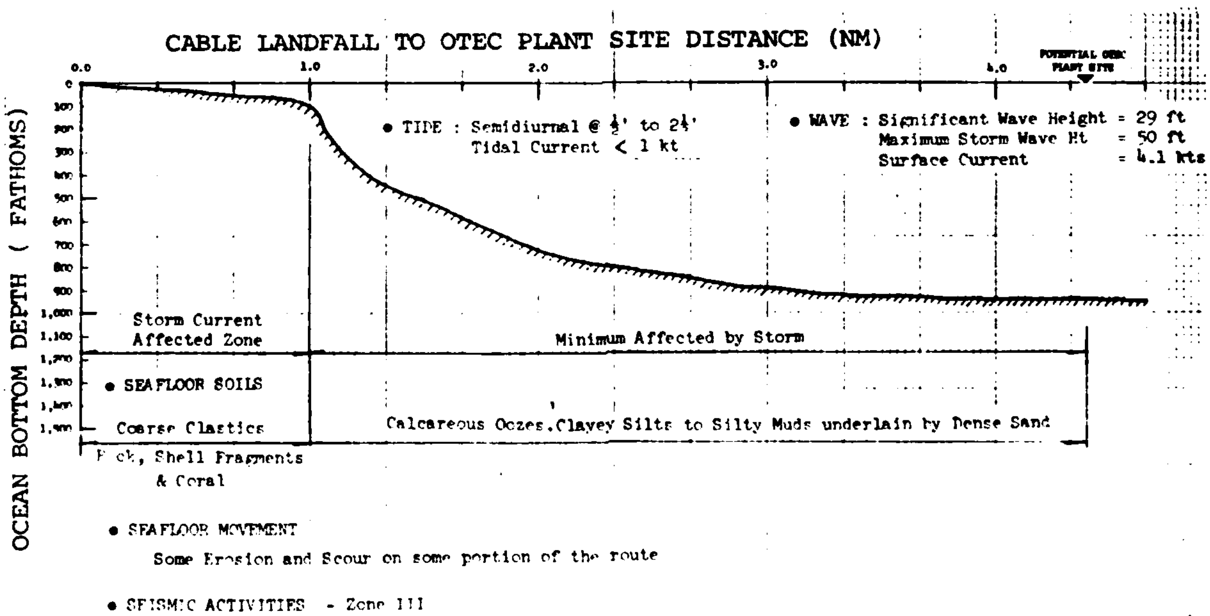


Figure 2.5 Environmental Characteristics - Natural Factors

Punta Yeguas, Puerto Rico

The profile over the seafloor along the cable route is shown in Fig. 2.5. Indicated here is a flat slope outshore from land for about 1.0 nautical mile and thence a sharp drop of about 2,000 feet, gradually flattening out to the plant site where the slope is 1 vertical to 30 horizontal.

Tide at this site is semi-diurnal but with considerable inequality in the heights of high and low water. Tides vary from 0.5 foot to 2.5 feet in height. Tidal currents over the site are of minimum significance amounting to a maximum of 1.0 knot.

The site lies in the path of westward moving North Atlantic tropical circulations and occasionally it experiences winds of hurricane force. The hurricane season generally begins in June and continues into November. During this period, several hurricanes can be expected to affect the site.

The sea bottom sediments for the flat slope out from shore a distance of less than 1.0 nautical mile are described as coarse clastics, consisting of rock and shell fragments and coral. The sea bottom sediments in the deep slope towards the site are described as calcareous oozes, clayey silts to silty muds underlain by dense sand.

Significant wave heights are given as 29 feet annually with a maximum of 50 feet during hurricane storms. These have been computed for the plant site and are deep water waves. The lengths of these waves (crest to crest) are about 520 feet and 900 feet respectively and water depth at the site is 5 to 9 times the wave length. It can be expected that these waves will move towards shore until they reach the area where water depth is about 1/2 the length of waves, (i.e., 260 feet to 450 feet deep). This is about 1.0 nautical mile from shore where the sea bottom begins its steeper slope from the shallow flat beach stretch. At this point the waves would tend to break, reform to a lesser height and break a second time as they approach shore.

The maximum resultant current velocity from storms can be expected to reach 4.0 knots in deep water; inshore in the shallow waters where breakers will occur it can be expected that this velocity may be exceeded. At the plant site and for the outer 2.5 nautical miles of the cable route the current produced at the sea bottom by a 4.0 knots surface current would be negligible. Sufficient sea bottom current to disturb soil particles laying on the bottom can then be expected from shore outward about 1.1 nautical miles.

The sea bottom for the first nautical mile from shore is expected to be hard (coarse clastics, consisting of rock and shell fragments and coral) so that a minimum of soil movement can be anticipated. From the 1.0 nautical mile point outshore, the sea bottom is expected to consist of gradually deepening sediments so that considerable bottom movement can be anticipated for the next 0.5 nautical mile approximately. Sea bottom slides can be expected on the slope beyond 1.0 nautical mile since the slope is approximately 1 to 2.

Along the north side of Puerto Rico there is an active major fault line which begins in Central America, forms an arc across the Caribbean Sea, extends north of Puerto Rico, then bends southeast beyond the Virgin Islands towards Venezuela. This area accounts for 0.9 percent of the world's seismicity (based on energy).

Figure 2.6 shows the man-made environmental factors affecting the potential OTEC plant site and sea bottom cable route. Ship traffic in and near the Puerto Rican site is estimated using ship data only; no information for this area was available from authorities in Puerto Rico. It is estimated that ship traffic is approximately 450 to 500 vessels per year, using ship weather reporting as a basis. This estimate may be too high, as there is considerable variability in monthly report counts through this zone. Ship traffic includes oil tankers and oil barges with tugs.

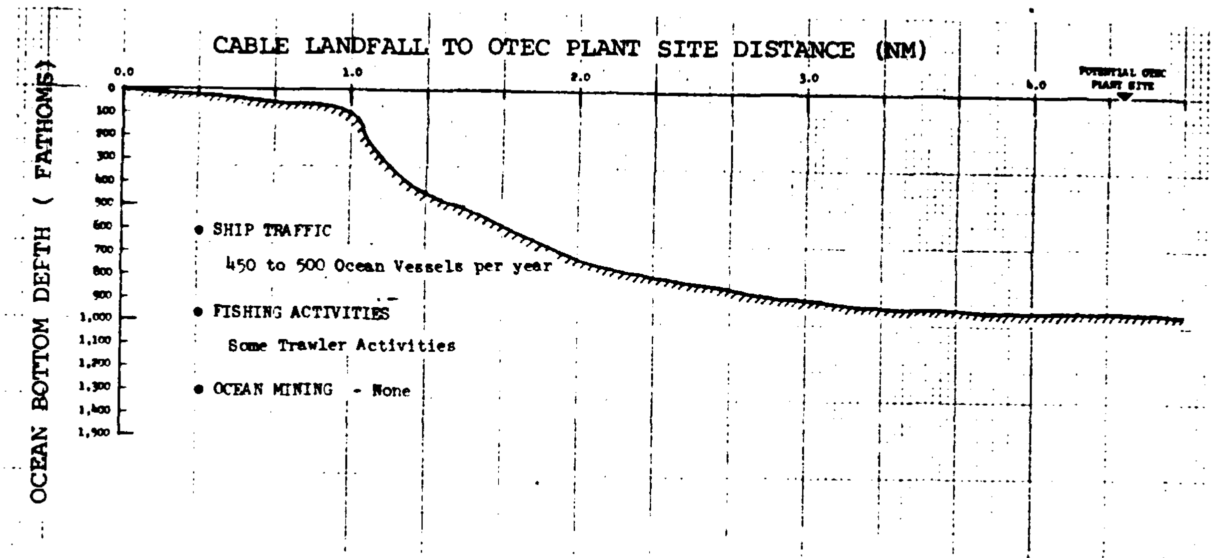


Figure 2.6 Environmental Characteristics - Man-made Factors

Punta Yeguas, Puerto Rico

The fishing fleet in the vicinity of Punta Yeguas is composed mainly of small local craft less than 25 feet in length, although about a dozen larger craft of the 50 feet class are known from nearby ports. There is some known trawler activity, with only limited fishing for snapper on the site itself. Handlining, gill netting and reef fishing are common, especially near Grappler Bank which is a favorite local spot. Some sport fishing is also known.

The marine sediments surrounding the potential OTEC plant site do not appear to contain any minerals with potential for mining. Though the Carribbean Sea is an area that has natural gas and oil reserviors, the southeast coast waters of Puerto Rico has been explored for oil and natural gas, but without success.

2.4 CABRAS ISLAND, GUAM

Coordinates for the plant site are 13°28.9'N, 144°40.3'E, and for the cable landfall are 13°28'N, 144°40.9'E, as shown in Fig. 2.7. Water depth at the site is 2,000 feet and the plant site is 1.1 nautical miles from shore.

There is no submerged cables or pipelines indicated near the plant site and cable route and the sea lanes for normal sea traffic are well offshore. The landfall is coral and is located close to Piti Canal. There are no other river outflows. Apra Harbor lies about 5.0 nautical miles away. A sewer outfall may be nearby.

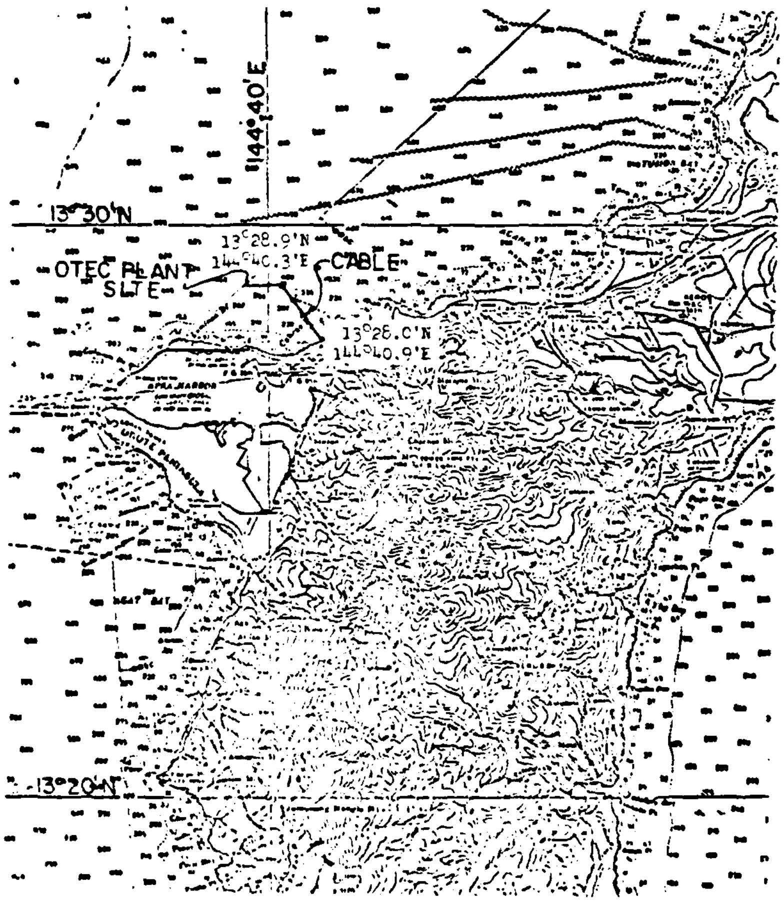


Figure 2.7 Potential OTEC Plant Site and Route

Cabras Island, Guam

The profile over the seafloor along the cable route is shown in Fig. 2.8. Shown in this figure is a relatively short flat sloping beach for less than 0.1 nautical mile from which the bottom then slopes more or less uniformly to the plant site at about 1 vertical to 2.5 horizontal.

Tide at this site is semi-diurnal but with considerable variation in the heights of high and low waters. Tides vary from a mean range of 1.7 feet to a range of 2.4 feet when the diurnal tides are prominent. Tidal currents over the cable route are of no great significance amounting to a maximum of 1.0 knot.

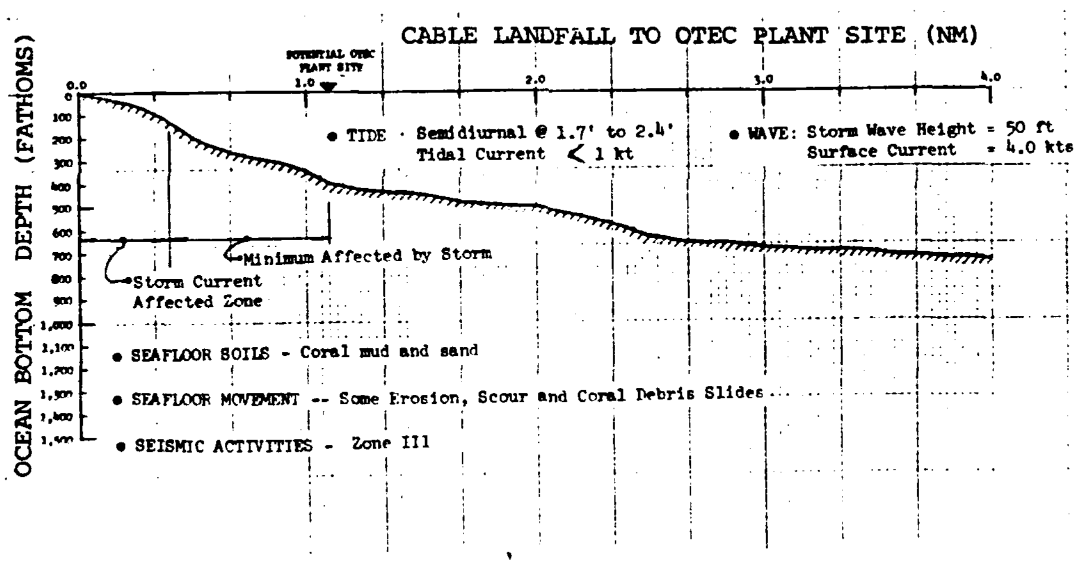


Figure 2.8 Environmental Characteristics - Natural Factors

Cabras Island, Guam

Cabras Island area, lying in tropical western North Pacific waters, is generally under the influence of the easterly trade winds throughout the year. In winter, the trades show a shift to northeasterly, when monsoonal flow between the Asiatic High and Australian Low reach their maximum. In summer, the trades become southeasterly, as thermal low pressure over Asia interacts with the intensifying North Pacific High.

The Intertropical Convergence Zone (ITCZ) lying between the North and South semi-permanent highs, lies north of the equator in summer. When the trade winds are at their greatest strength, and the ITCZ is most active, tropical cyclones may develop at this latitude. This is most likely in the late summer and fall months. Gales occasionally occur in winter, associated with the passage of typhoons. Typhoon frequency is fairly high in this area, with an average of one storm per year forming in or near the Marianas, or moving through the area. During the summer rain season, thunderstorms are fairly common in the area and are frequently accompanied by brief squalls. Maximum observed and reported winds are about 48 knots.

The sediments in the ocean at this site consist of coral, mud and sand which grades downward and outward into Globigerina ooze, which in turn grades into Radiolarian ooze and red clay at very great depths. A number of samples have been taken by U.S. vessels in the past years around Guam. One sample taken off the northerly end of Guam in 810 feet of water consisted dominantly of Foraminifera, comminuted coral, fine sand and silt, with some Halimeda debris. No ledges of bedrock were found in the dredging samples. The beach sand of Guam along the northerly part of Guam are white or buff sands that consist of calcareous organic remains.

A reasonable assumption of significant wave heights would expect wave heights of 50 feet during typhoon storms. These would be for the plant site

and would be deep water waves. The length of these waves (crest to crest) is about 900 feet and water depth at the site is about 2 times the wave length. These waves will move towards shore until they reach the area where water depth is about 1/2 the length of the waves, i.e., 450 feet. This is about 0.2 nautical miles from shore. It appears that the sea bottom slope is fairly uniform at about 1 in 3. At this point the waves would tend to break, reform to a lesser height and break a second time as they approach shore.

The maximum resultant current velocity from storms can be expected to reach 4.0 knots in deep water; inshore in the shallow waters where breakers will occur, it can be expected that this velocity may be exceeded. At the plant site and for the outer 0.7 knots surface current would be negligible. Sufficient bottom current which will disturb soil particles laying on the sea-bottom can then be expected from shore outward about 0.4 nautical mile.

The sea bottom is expected to consist of coral, mud and sand except for a short distance from shore where coral outcropping occurs, so that soil movement can be anticipated. Bottom slides are not expected on the slope since the slope is approximately 1 in 3.

Guam and the Marianas Islands separate the Philippine Sea, one of the deepest ocean basins from the Pacific Ocean. To the west of the island is a major ocean trench; the maximum Pacific Ocean depth has been recorded in this trench. Shallow quakes between the trench and the islands occur, but the greatest seismic activity is in the North Marianas Islands. These islands along with the North and South America West Coast form the Circum-Pacific Belt. This belt accounts for 75.6 percent of the world's seismicity. The Marianas Islands, represent 3.9 percent of the world's seismicity. The last major quake occuring in Guam was in the year 1862, based on data to 1974.

Figure 2.9 shows the man-made environmental factors affecting the poten-

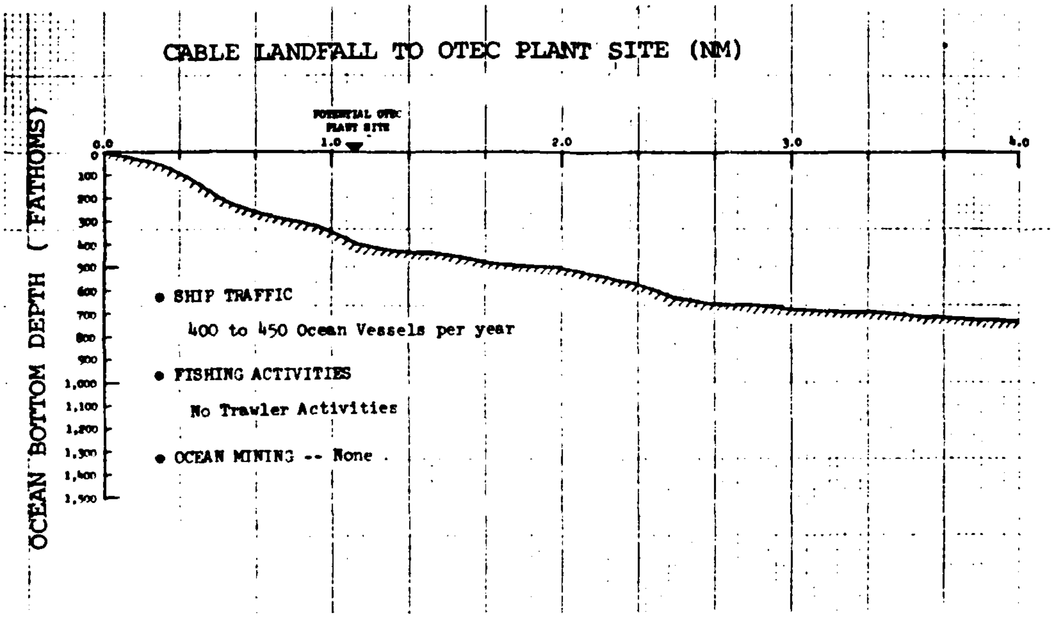


Figure 2.9 Environmental Characteristics - Man-made Factors

Cabras Island, Guam

tial OTEC plant site and the sea bottom cable route. Although navigational procedures in this area restrict it from general traffic, it is estimated that 400 to 450 ocean vessels pass the site to the seaward each year. This figure is based on limited ship report data for only portions of the years searched.

The entrance to Apra Harbor lies between the terminus of a 1.5 mile breakwater extending westward from Cabras Island and the reef fringing the north side of Orote Point, located approximately 1.8 miles southwest of the breakwater terminus. Ships approaching the harbor from the north are advised to keep five miles offshore until Orote Point bears 180°. Then a southerly course can be steered to the entrance. If these sailing directions are followed, ship traffic using Apra Harbor will maintain a distance at least two miles from the

plant site.

All port activities on Cabras Island are confined to its southern shore. Little, if any, activity is indicated on the north shore, except for the breakwater to the west of the island and an occasional small vessel near the site.

Within the 1.1 nautical mile distance offshore Cabras Island there is only local small boat fishing. There is no indication of trawler activity.

Guam, including the potential OTEC plant site, is surrounded by coral reefs, and calcareous formations. These reefs contain calcium carbonate which is a potential ocean mining mineral. Calcium carbonate is used in the chemical industry and also the construction industry to produce cement.

2.5 WEST COAST OF FLORIDA, TAMPA, GULF OF MEXICO

Coordinates for the proposed plant site are 27°40'N, 85°30'W and for the cable landfall are 27°52.5'N, 82°51'W, as shown in Fig. 2.10. Water depth at the plant site is 3,280 feet and the site is 145 nautical miles from the shore.

The plant site lies about 20 to 30 nautical miles outshore of a Disused Explosive Dump Area which will be crossed by the bottom cable. An Explosive Dumping Site lies 30 nautical miles outshore, as does a Missile Test Area at about the same distance. There are bottom obstructions near the cable route, as well as artificial fishing reefs.

No pipelines are indicated in the area. The plant site lies in the Sea Lane from Pensacola, Florida to Key West and the Sea Lane from Mobile, Alabama, to Key West lies just offshore the site. Landfall is on a sandy beach named Indian Rocks, between Clearwater and St. Petersburg.

The profile over the seafloor along the cable line is shown in Fig. 2.11. The scale used in this figure is 1 vertical to 30 horizontal. Indicated here

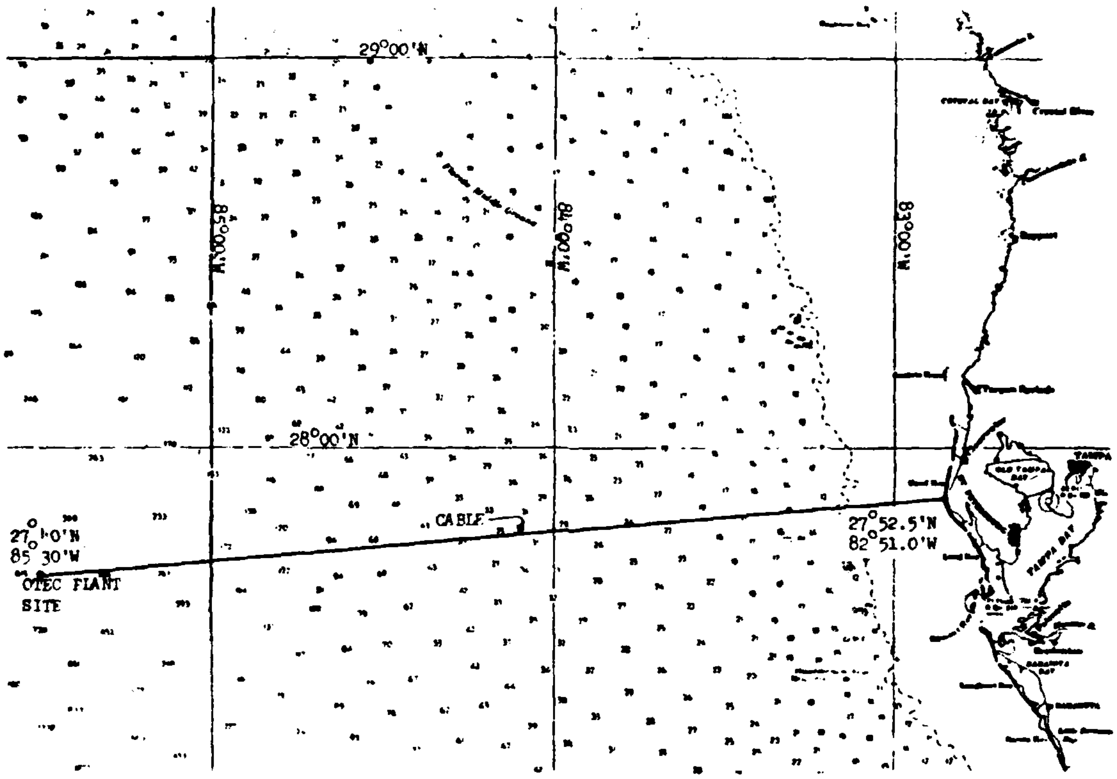


Figure 2.10 Potential OTEC Plant Site and Route

West Coast of Florida, Tampa

is a very flat slope for 70 nautical miles from shore, about half the distance to the plant site. Beyond this point the slope gradually increase to about 1 in 10 at the site.

Tide at this site is semi-diurnal but with considerable inequality in the heights of high and low waters. Tides vary from 0.1 foot to 3.0 feet in height. Tidal currents over the cable route are no great significance amounting to a maximum of 1.0 knot.

The cable landfall site is at Indian Rocks Beach, a white sandy beach area. The Florida Middle Ground or Florida Platform is between the shore and the

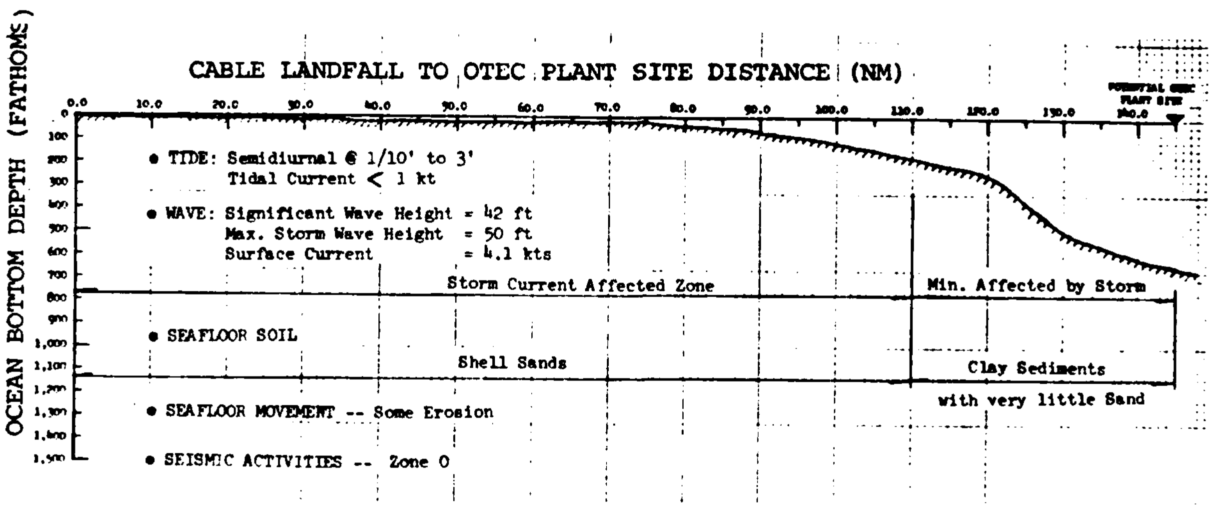


Figure 2.11 Environmental Characteristics - Natural Factors

West Coast of Florida, Tampa

Florida Escarpment. This platform is a gradually sloping submarine terrain which thousands of years ago was part of the dry Florida Peninsula. As the sea water level rose, the fresh water swamps were gradually taken over by the saltwater. Thus the platform sediments are basically of the same composition of the Peninsula. A shallow area less than 10 feet deep of mud is present; the sediments are shell sands with concentrations of heavy minerals. The sand contains the minerals quartz, feldspar with an average of over 80 percent of the grain's diameters between 0.062 to and 2.0 m.m. As the platform approaches the escarpment, foraminiferal remains are present in the deep water bottoms. This is the typical marine sediment until the Florida Escarpment is reached.

The Florida Escarpment separates the Florida Platform from the deep ocean basin of the Gulf of Mexico. The escarpment is an area of dead carbonate reefs. At the plant site in the deep Gulf basin there is mostly carbonates and clay sediments in the upper seven meters. There is no silt, with very little sand, and some Globigerina ooze present at the surface.

Significant wave heights at the plant site are given as 42 feet annually and a maximum of 50 feet during hurricane storms. The lengths of these waves (crest to crest) are about 750 feet and 900 feet respectively and water depth at the site is then 3 to 5 times the wave length. The waves will move towards shore until they reach the place where the depth is about 1/2 the length of waves, (i.e., 375 feet to 450 feet deep). This is about 90 to 100 nautical miles from shore where the sea bottom begins its steeper slope. At this point the waves would tend to break, reform to a lesser height and break a second and more times as they approach shore.

The maximum current velocity resulting from storms can be expected to reach 4.0 knots in deep water; inshore in the shallow waters where breakers will occur it can be expected that this velocity may be exceeded. At the plant site and for the outer 35 nautical miles of the cable route the current produced at the sea bottom by a 4.0 knot surface current would be negligible. Sea bottom current sufficient to disturb soil particles laying on the bottom can then be expected from shore outward about 110 nautical miles.

The sea bottom from shore outward 110 n.m. is expected to have sediments of shell sands with concentrations of heavy minerals about ten feet deep so that movement of the soil at the sea bottom can be anticipated for this distance. Bottom slides are not anticipated for the slope over the entire 145 nautical miles is relatively flat.

The eastern Gulf of Mexico is not near any major fault line, therefore it

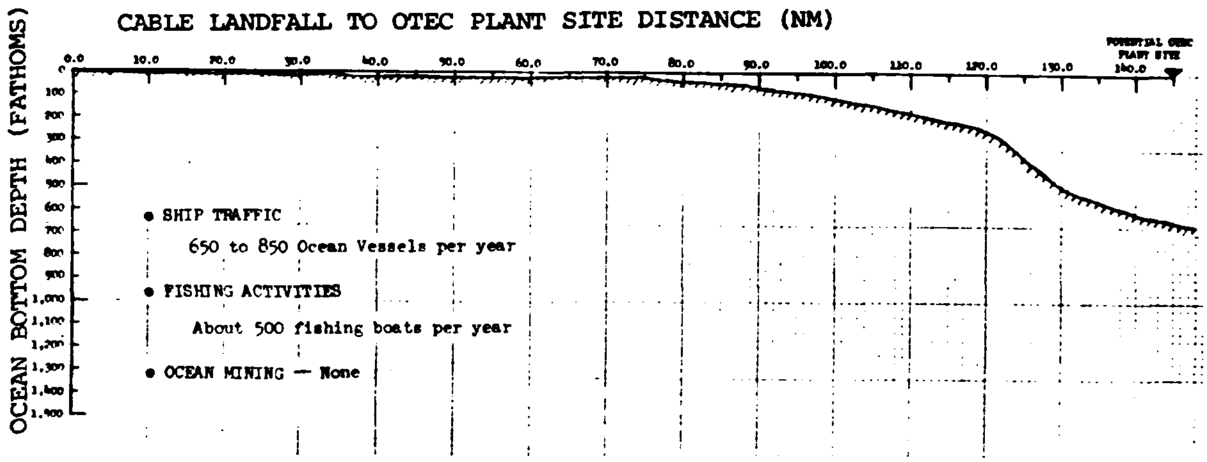


Figure 2.12 Environmental Characteristics - Man-made Factors
West Coast of Florida, Tampa

is a low seismic area.

Figure 2.12 shows the man-made factors affecting the potential OTEC plant site and the sea bottom cable route. Ship traffic through this area is estimated to be 650 to 850 ocean vessels per year. This count does include some of the smaller vessels which trade between Gulf Coast ports and Tampa. The large spread in the estimate is due to the consideration of ship reports and the Port of Tampa arrival and departure information. Ship traffic includes oil tankers and barges.

There is extensive fishing activity, both commercial and recreational in this area, including trawlers, charter boats, and private sport fishermen, mostly from the Port of Tampa. There are a number of artificial reefs as

close as 20 miles and there is the popular Middle Ground, a natural rock formation, located about 90 miles from shore. Fishing activities include commercial scallop dredging, a small amount of recreational scalloping inshore, shrimping, bottom, reef and long line fishing.

There are about 400 fishing boats less than 5 gross tons and about 100 boats over 5 gross tons, which are mostly tuna boats. About 1,300 fishermen are engaged in this activity. About 11 million pounds of fish are produced commercially in the Tampa area annually. The sponge industry is now very small but there are signs of regeneration.

On the Florida Escarpment in the Gulf of Mexico, particularly in the vicinity of the OTEC plant site there are reefs of dead calcareons. These calcareons formations are a potential calcium carbonate mining area. The Gulf of Mexico waters are a rich oil and natural gas producing area. Presently, most of the offshore drilling is located in the northern and western Gulf of Mexico. Natural gas and oil reserviors may be discovered in the eastern Gulf of Mexico, especially in the deeper waters west of the Florida Escarpment as exploration for oil and natural gas continues.

CHAPTER 3. BOTTOM CABLE HAZARD ANALYSIS

3.1 INTRODUCTION

A hazard is a natural or manmade phenomenon that is potentially a source of damage to a cable system. Usually the time of occurrence and the extent of damage cannot be predicted for an individual case; however, overall probabilities can be assumed. General techniques for alleviating hazardous conditions in the design of a cable system are: (1) to avoid the hazard, (2) to accept a calculated risk, (3) to provide protection for the assumed "worst case" during the cable design life (30 years in this study) and (4) lay a redundant cable.

3.2 NATURAL HAZARDS

The water depths and slopes along the cable routes are important items of topographic and hydrographic information. A shallow water depth is associated with higher wave action on the seafloor as well as stronger currents carrying more bottom sediment which can produce chafe and consequent corrosion. The higher oxygen content and more abundant plant and animal life of the shallower waters will increase the incidence of biological fouling and attack and subsequent corrosion. Certain seafloor areas are more susceptible to seismic activity and submarine slides which can both displace seafloor areas and cause cable failure. Clearly, these areas should be avoided if possible for cable installation.

3.2.1 CHAFE AND CORROSION

Chafe and corrosion of a cable are caused by water current and wave-induced motions. The chafing process removes the outer protective layer or coating of a cable, thus exposing the steel strength wires and making them susceptible to corrosion by the sea water. Chafing occurs by the action of

abrasion (a) by the sand or gravel moving across the cable by current or wave driven motions or (b) by the grating back and forth of a cable over hard rock surfaces, when driven by currents or wave motions. A cable can be lifted or dragged across a seafloor by the orbital action of waves. Currents and waves can erode seafloor and remove any protective seafloor cover where a cable is buried, thus exposing a cable to the same hazards as a cable laid on the seafloor without protection.

The maximum hazard exists when (a) water currents are the greatest (b) when wave heights are the highest (c) when wave periods are the shortest and (d) when these actions of (a), (b) and (c) are in a direction perpendicular to the cable line.

It is particularly important to identify the existence of seafloor surfaces that have hard consolidated strata such as gravel, cobble or boulder layers that could potentially be subject to scour and exposure of the bedrock. If the cable is laid on a sandy bottom the cable will usually sink some short distance below the soil surface under the influence of wave action if sufficient slack is left in the cable to allow it to sink as the soil particles move beneath it. If, however, all of the sand over a hard seafloor strata is removed, then the cable will be directly subject to wave and current forces as well as to abrasion by being moved over the rock.

Corrosion can also be induced biologically through the fouling by bottom organisms such as bryozoa, shell and sponges to a degree that could impair or interfere with cable operations but these processes are usually limited to water depths of less than 10 fathoms (See reference 6). The more common types of biological fouling found to affect cable installations are kelp and coral. If the cable is not well buried then kelp can attach itself to the cable. Kelp has been observed at depths of 40 fathoms but the heaviest growth

seems to occur in less than 8 fathoms. There are reports of coral growth on cables located in tropical waters but these growths usually appear as small, isolated clumps, averaging about 6 inches in diameter.

The hydrodynamic effect of large amounts of kelp or coral attached to a cable can be significant. In areas of very active coral growth the cable may become completely encased in a coral formation. However, the growth rate of coral is slow even in the active tropical areas (about 1/2 inch per year).

3.2.2 SUBMARINE LANDSLIDES

Submarine landslides are the phenomenon of the mass movement of seafloor sediments caused by unbalanced gravity forces. Submarine landslides are of particular importance in the delta areas (where rivers empty into the ocean) because of their soil characteristics which are as follows:

- High rates of sedimentation (excessive sedimentation loading)
- Sediments of very low shear strength unconsolidated clay
- Rapid biochemical degradation of organic materials in the deposits (formation of large quantities of in-situ sedimentary gases, primarily methane and carbon dioxide.

The unbalanced gravity forces causing submarine landslides in the delta areas are the pressure changes on the seafloor associated with the passage of storm or hurrican waves. The magnitude of this pressure change, Δp, which is in phase with the wave, depends on the wave length, the depth of water and the wave height. The differential loading of the surface of an underwater ground surface will impose stresses on underlying soil and, if the stresses exceed the strength of the soil, significant displacement may occur which may introduce tension forces in a cable sufficient to cause failure.

Reference 10 presented an analytical approach to compute the depth of submarine landslide induce by wave forces. The computation procedures may

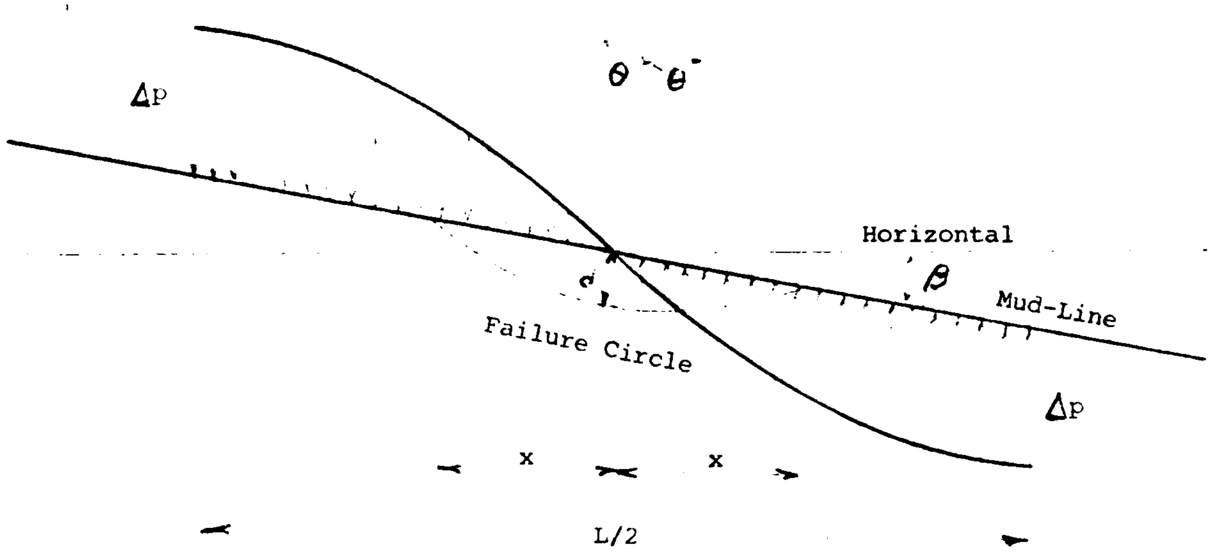


Figure 3.1 Geometry of Assumed Surface of Sliding

be depicted in Figures 3.1 to 3.3. In Figure 3.1, a sinusoidal pressure change of amplitude, Δp, and wave length, L, is assumed to act on the surface of the ocean floor. A possible failure mechanism of sliding along a circular arc failure surface was assumed in order to compute the depth of the failure circle, d. In the Mississippi Delta areas, the relationship between pressure change on the seafloor and the maximum depth of the failure circle is shown in Figure 3.2. In the figure, γ is the submerged unit weight of the overlying sediments, β is the slope angle of the seafloor (shown in Figure 3.1), and κ is the ratio of the undrained shear strength, Cu, at a depth z, to the pressure associated with the submerged weight of overlying sediments (i.e., κ = Cu/ z). Figure 3.3 shows that for a deep-water wave 30 ft high with an initial wave-length of 600 ft, the pressure change on the seafloor is greater than 200 lbs/

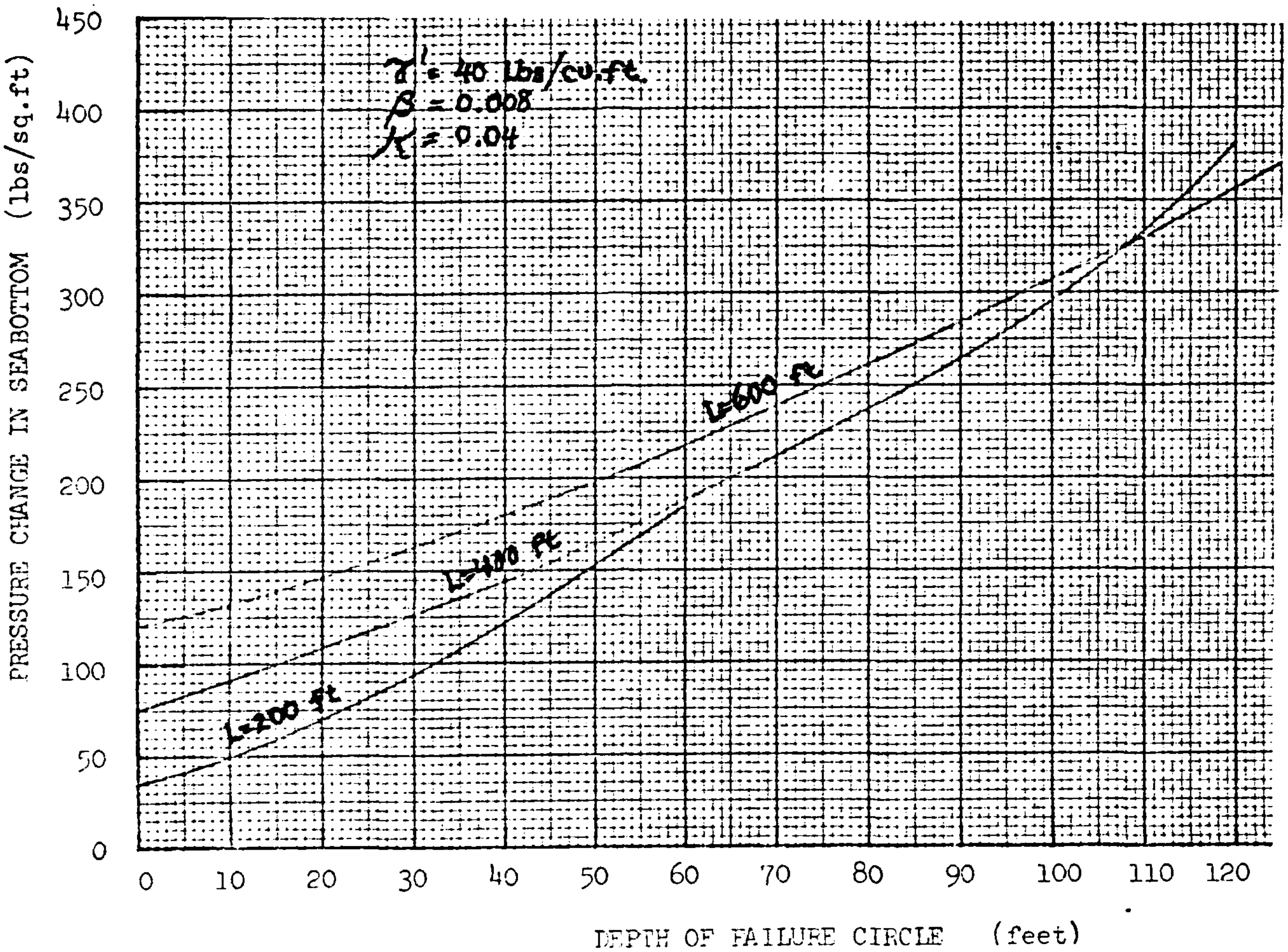


Figure 3.2 Relationship Between Pressure Change in Sea Bottom And the Maximum Depth of Failure Circle for Various Wavelengths

sq. ft. for water depths between 10 ft. and 200 ft. while a peak value of 630 lbs/sq. ft. is found at a water depth of 50 ft. According to Figure 3.2 this wave may cause submarine landslide to the depths of 50 ft. to 160 ft. below mudline.

When the underwater slope in a delta area is more than 1 degree (1 vertical to 58 horizontal) then the site is potentially hazardous.

In an area that is not in a delta or seismic zone then a slope greater than 4 degrees (1 vertical to 14 horizontal) should be treated as potentially unsafe.

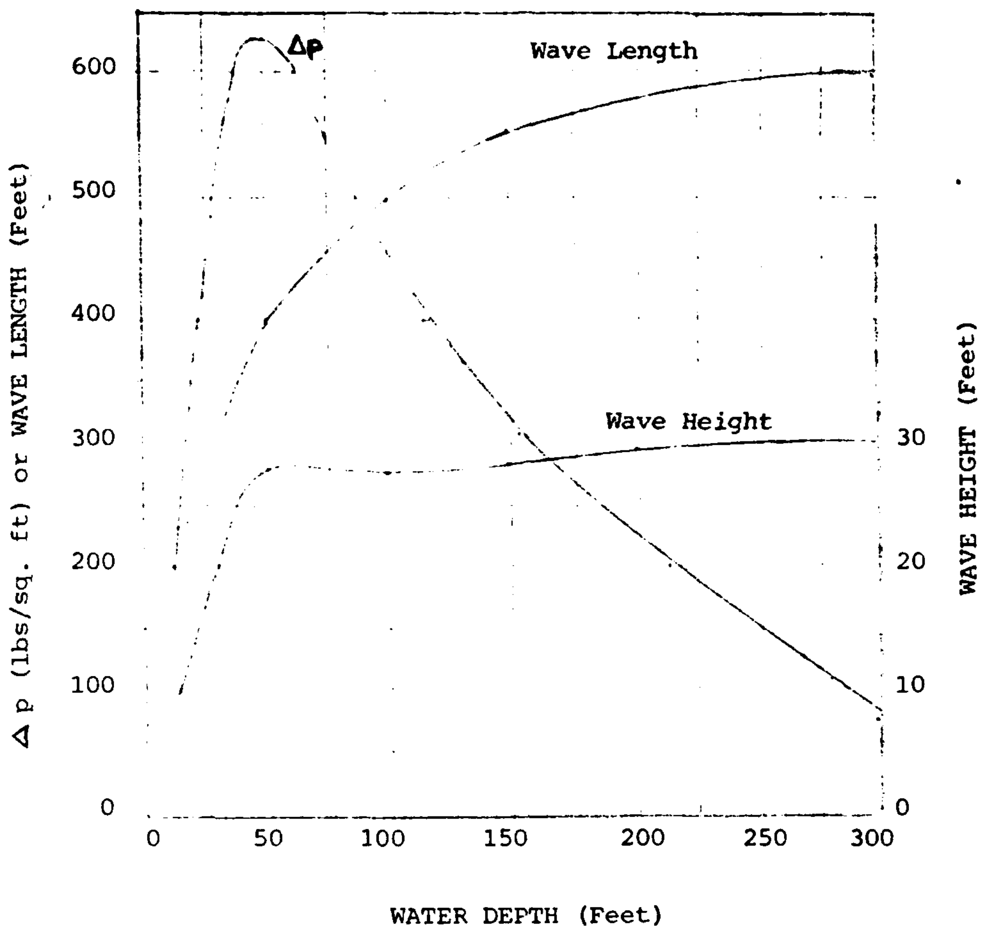


Figure 3.3 Relationship among Δ p, Wave Length, Wave Height and Water Depth for 30 ft Deep Water Waves at 10.9 second Period Approaching Shore

3.2.3 EARTHQUAKES

Submarine earthquakes incite seismic forces that may cause sliding of one face of a fault zone relative to the other (usually only a few feet relative displacement), or cause the slumping or sliding of blocks or sheets of seafloor (displacement of a few hundred feet). Earthquake vibrations can trigger a slow slide and turbidity current.

Breaking tensions can be induced when the cable is caught up and included in the moving seafloor mass. Cables that traverse an initially unstable sea-

floor, even if buried 3 or 4 feet deep, would undoubtedly be broken by any sizeable seafloor movement. In a seismic area any underwater slope of more than 3 or 4 degrees (1 vertical to 14 to 19 horizontal) should be treated as a potentially unsafe area. It is always wise to investigate the area for past seabed earthquake occurrences and the risk of future earthquakes.

3.2.4 MISCELLANEOUS (Wind Storm, Brushwood, Falling Rock, Teredo, Cable Suspended over Rock, etc.)

Wind storms (including hurricanes, typhoons, squalls, etc.) can generate large currents and waves that induce large drag and lift forces on exposed cables. Where the cable is near a river mouth that is flooding, great amounts of brushwood and trees are discharged into the ocean. If this flood debris and other flotsam becomes entangled with the cable then the current forces which are proportional to the submerged area will become greatly increased.

Cable failure by a rock avalanche is considered rare. However, large rock, rock outcrops and boulders are obstacles that should be known or avoided. Cable suspensions more than 60 feet are common on rocky seafloors. These freely hanging spans will induce tensions in the cable proportional to the square of the span length.

There was one reported incident of failure damage to a communication cable by a whale that apparently was feeding along the seafloor and its lower jaw went beneath the cable laying near the surface (Ref. 6).

Marine organism generally are not a problem with present polyethylene-insulated cables. However, teredo attack on these cables can be invited by attaching materials susceptible to teredo attack (manila or hemp line, or canvas) to the cable (Ref. 7 and 8). Once a mollusk is attached to a cable some penetration may be attempted but the net effect of marine organisms on the performance of a well-designed cable system is minimal.

3.3 MANMADE HAZARDS

3.3.1 FISH TRAWLING/CABLE GRAPNELING/OCEAN MINING

(a) Fish Trawling

Two types of seafloor fishing gear are commonly used by trawlers.

(1) OTTER-TRAWLS

Figure 3.4 shows the configuration of the otter-trawl equipment which consists of the fishing net, otter-boards and the towing wires. Damage to the cable can occur when cables are snagged by the otter-boards that are dragged along the seafloor to keep the mouth of the trawl net open. The otter boards are constructed of hardwood boards reinforced with steel plates. They weigh approximately 1-1/2 tons each. The towing wires are approximately 1 to 1-1/4 inches in diameter with breaking strengths of about 30 to 40 tons. The normal fishing speed is 4 to 5 knots in waters as shallow as 120 feet.

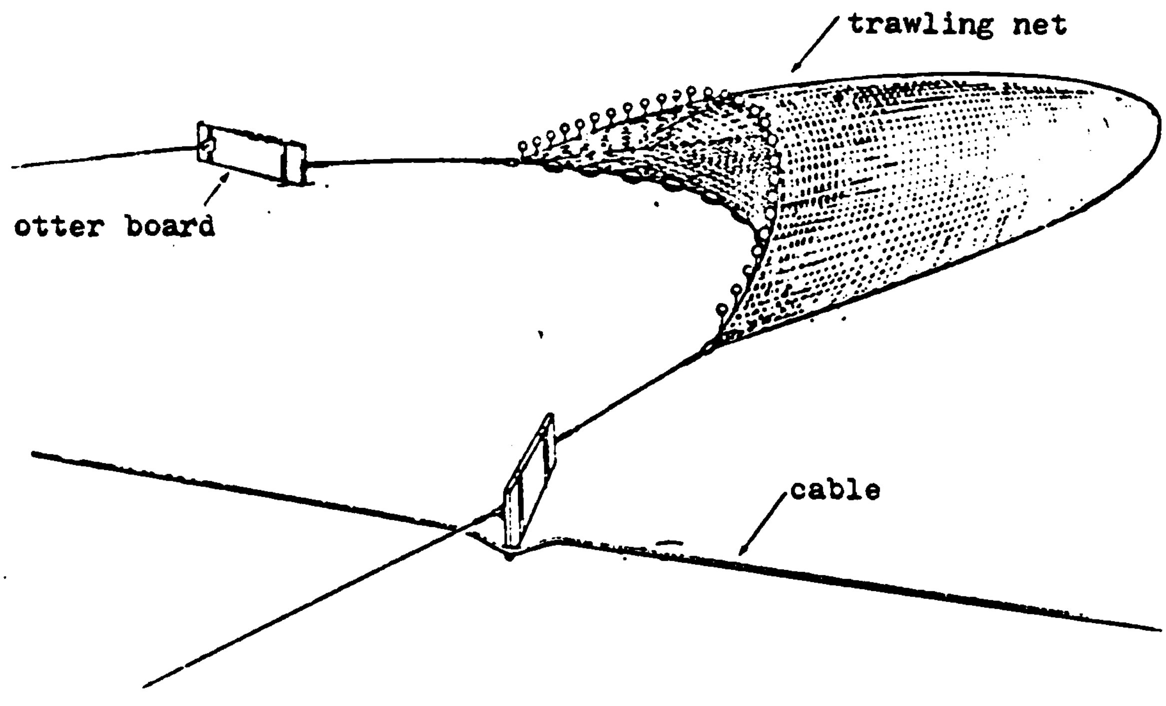
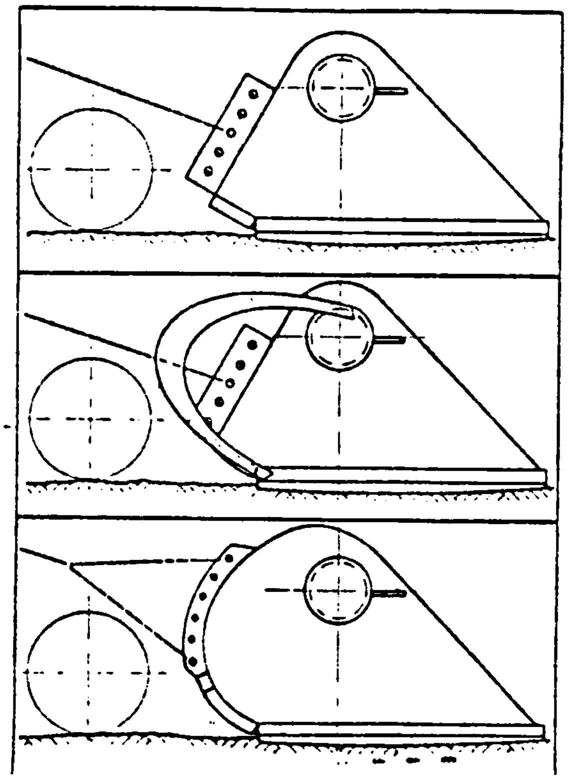


Figure 3.4 Interference of Trawling Otter Boards and Submarine Cables



(a) Beamtrawl shoe as used in the Norweigian Experiments. A 16" Ø pipe-line is also shown.

(b) Modified beamtrawl shoe; a hoop is welded in front.

(c) Modified beamtrawl with double bridles.

Figure 3.5 Side Views of a Beamtrawl Shoe Used in North Sea Areas

(2) BEAM TRAWLS

The beam trawl gear consists of the fishing net, trawl beam and shoes, and tow wires. The average beam length is about 32 feet (10 meters). The shoe is made of cast iron or welded steel plates as shown in Figure 3.5. The average total weight of a fully rigged beam trawl is about 4 to 5 tons. However, the heaviest beam trawl gear can weight about 6 tons.

When the fishing gear is lost, the trawlers usually use old anchors dragging around the seafloor area to recover it. The average weight of the drag-anchor is about 1,100 pounds (500 Kg). Figure 3.6 from reference 23 shows the depth of penetration into seafloor soil by the trawler fishing gear and the

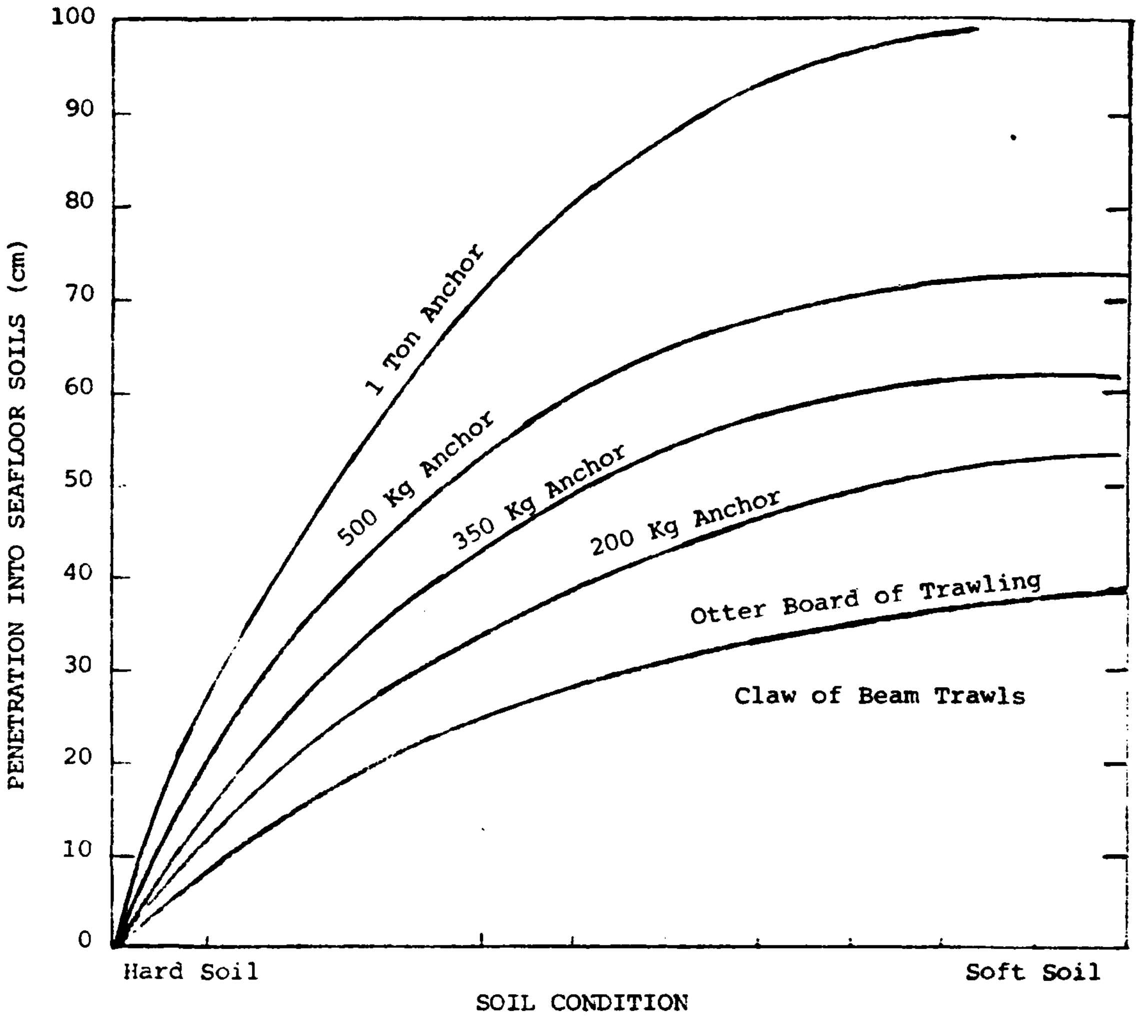


Figure 3.6 Penetration of Fishing Gear and Anchor

recovery drag-anchors. According to the curves shown in the figure, the beam trawls barely penetrate into the seafloor. The maximum penetrations of the otter boards and the 500 Kg (1,100 pounds) drag-anchors are, respectively, about 40 cm (1 foot 4 inches) and 73 cm (2 feet 5 inches).

3.3.1 (b) CABLE GRAPNELING

Cable grapnels are used to locate and bring a cable to the surface for repairs. Figure 3.7 shows several standard types of grapnels each suited for different conditions. In general, a grapnel is used to hook a cable by towing the grapnel along the ocean bottom from a cable ship. Normally, the grapnel

should be towed in a direction so that it approaches the cable at nearly a right angle. This presents the best opportunity for the grapnel to hook and engage the cable. Rope is usually used to tow a grapnel. The required length of grapnel rope depends on the water depth, rope weight and hydrodyamic properties, ship speed and bottom tension. The towing speed is usually limited to less than 2 knots since the greater the speed, the more the line tends to lift away from the bottom. Heavy chain pendants are frequently used to assist in keeping the grapnel depressed.

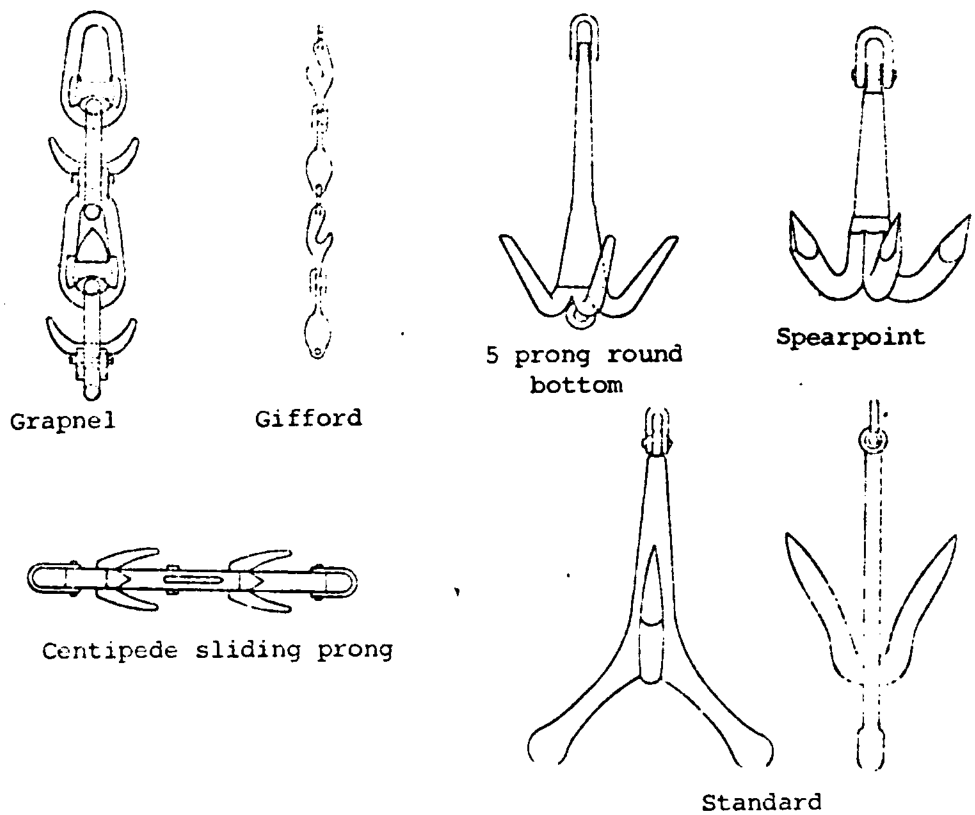


Figure 3.7 Types of Grapnels

3.3.1 (c) OCEAN MINING

Mining mineral from the seafloor has long been attempted through the centuries, but not until recently have business corporation organized to develop the technique and methodologies for large scale mining operation. The main factors affecting future ocean mining development are:

- Economical feasibility to compete with land resources
- Trans-ocean logistic problems in handling ores
- Pollution control resulting from mining and ore processing
- Mineral rights and the Law of the Sea Treaty negotiation

Table 3.1 summarizes the current knowledge of ocean mining activities. It is seen that ocean mining industries are still limited to certain locations for specific minerals except the mining for sand and gravel which is active in

Table 3.1 Types of Ocean Mining

Source	Location	Type of Mineral	Operating Water Depth (feet)	Note
Ref. 5	World Wide	Sand; Gravel	10 to 140	•Hydraulic suction and dredge
Ref. 5	Thailand; Indonesia; Malaysia	Tin	85 to 135 235 200	•Bucket dredge •Hydraulic dredge •Grab dredge
Ref. 5	Australia	Iron Sand; Gold	10 to 130	•Dredge
Ref. 11, 12, 25	Georgia/Florida Blake Plateau	Manganese Nodules	2,500 to 27,000	•Airlift hydraulic suction and dredge •Experimental work only
Ref. 11, 12, 25	Pacific Ocean	Manganese Nodules	15,000 to 18,000	•Airlift hydraulic suction and dredge •Experimental work only

many parts of the world. The table also shows that the mining operation for sand, gravel, tin and iron ores is up to about 250 feet water depth. The mining of manganese nodules in the future (Figure 3.8) will be concentrated on a large flat plateau area in the water depth of 15,000 to 18,000 feet (Ref. 25). The mining of manganese nodules should not interfere with the OTEC plant and transmission cable installation.

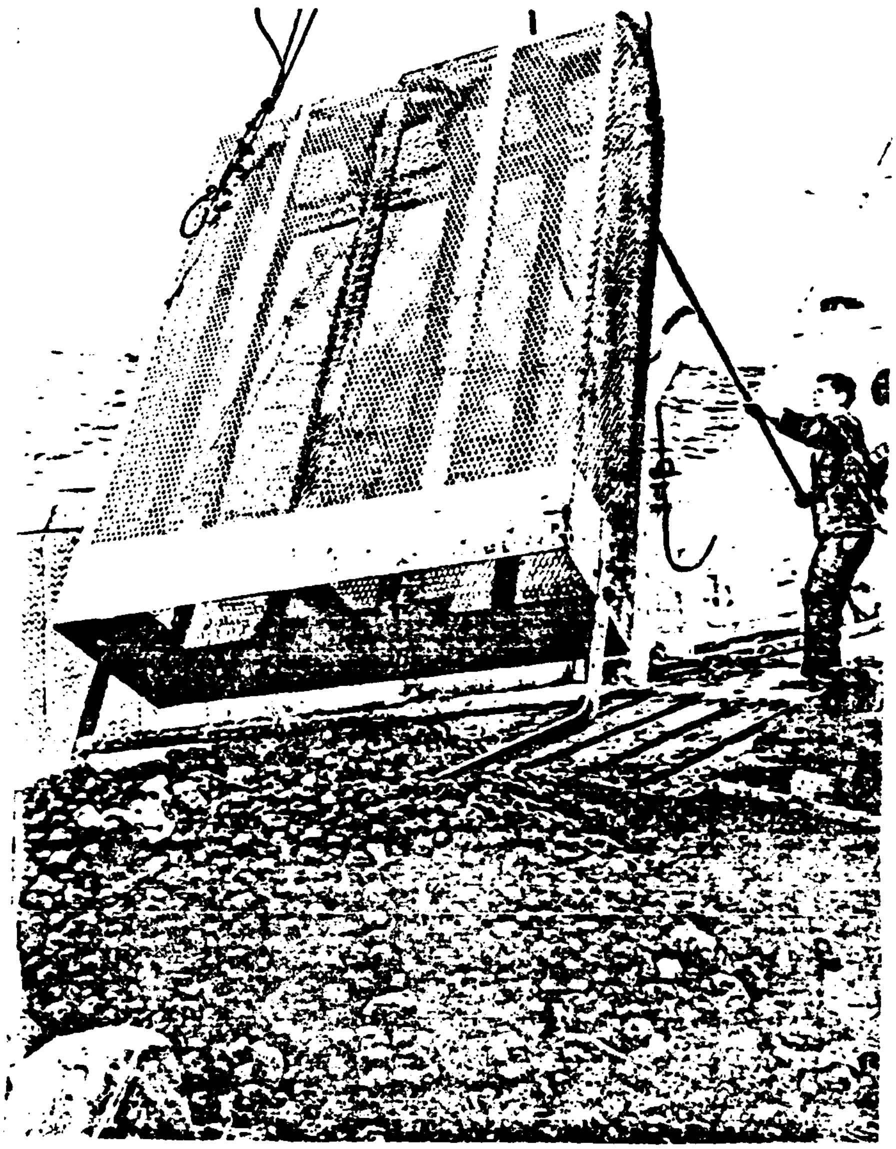


Figure 3.8 Unloading A Wire Dredge Basket Filled With Nodules Recovered From The Seabed After A Television Survey.

3.3.2 SHIP ANCHORS

The OTEC Submarine cable may be damaged by a ship anchor as the anchor is being pulled horizontally during setting, retreiving or dragging. The damage occurs as the anchor engages and slides along the cable which may cut and pull apart the cable external armor layer and internal core. The degree of this hazard is characterized by the frequency of various size vessels dragging their anchors in the vicinity of the cable. Of course, larger ships will have larger anchors that will bury deeper and have the capability for more damage when engaging a cable.

Ship anchors are used to develop holding power on the seafloor for mooring a floating body permanently or temporary on site. The major factors affecting the anchor holding powers are:

- Anchor weight
- Anchor shape (or type of anchor)
- Soil characteristics at the anchor site
- Anchor traveling distance
- Angle of chain connecting
- Fluke angle
- Fluke areas

Figures 3.9 and 3.10 illustrate the typical traces of an anchor holding power as the function of anchor weight, travel distance, fluke angle, and the soil characteristics. In sandy bottom (Fig. 3.9), an anchor in almost all cases develops its full holding power at about 50 feet of traveling distance. In mud bottom (Fig. 3.10), an anchor in almost all cases develops about 80% of its holding power at 50 feet traveling distance and full (100%) capacity at about 150 feet.

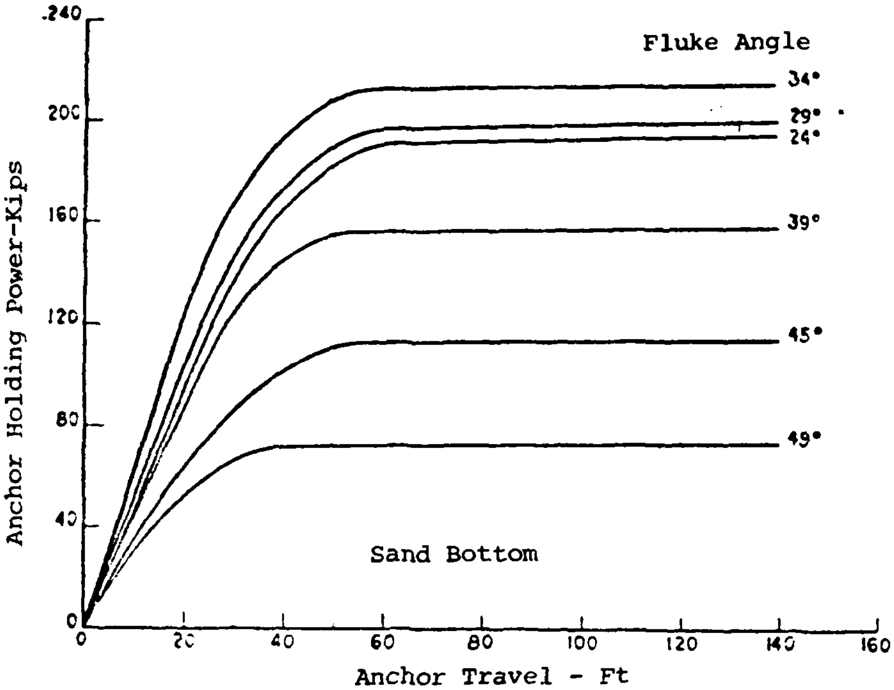


Fig. 3.9 Anchor Holding Power vs. Traveling Distance in Sand
(Test Data on 18,000 lbs Navy Anchor)

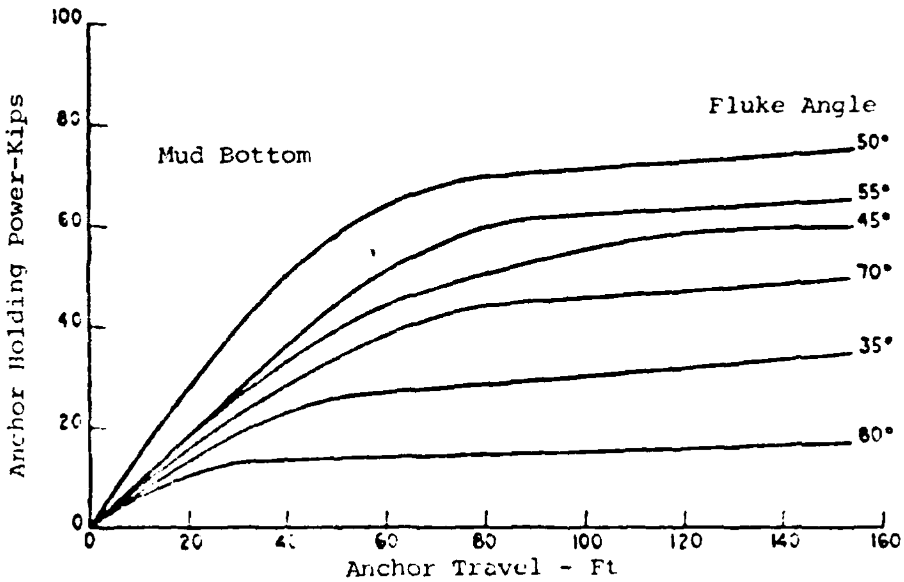


Fig. 3.10 Anchor Holding Power vs. Traveling Distance in Mud
(Test Data on 2,270 lbs Commercial Type Anchor)

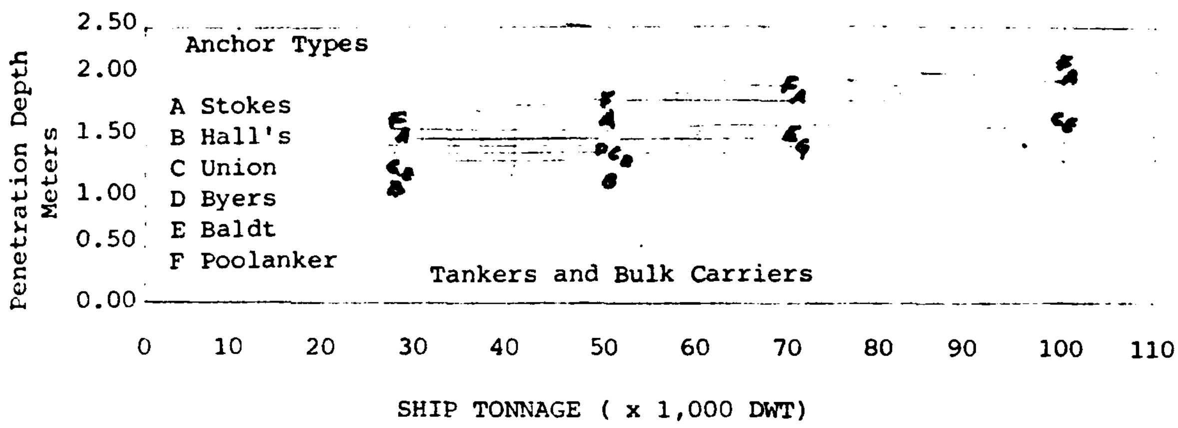


Figure 3.11 Relation Between Ship Tonnage and Penetration Depth of Anchors in Sandy Bottom

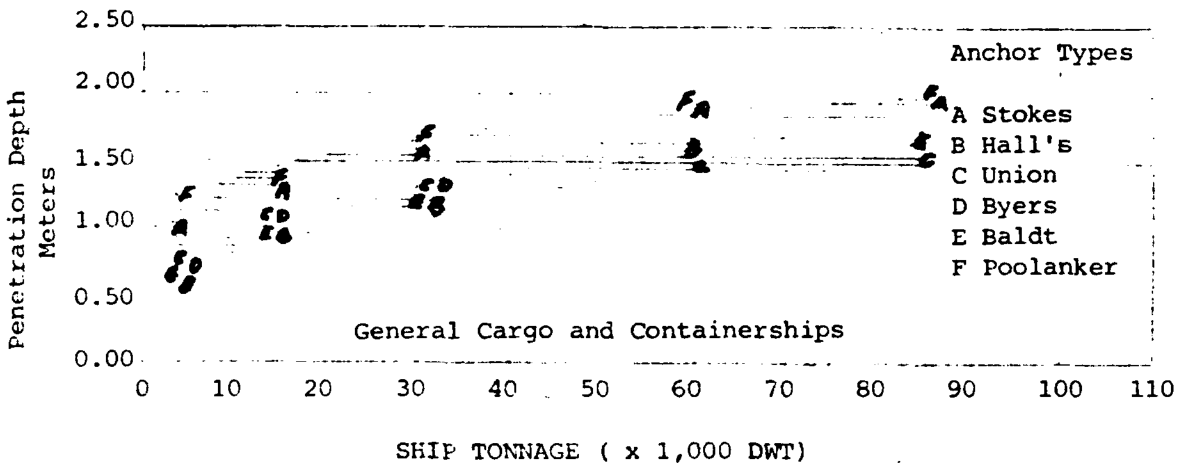


Figure 3.12 Relation Between Ship Tonnage and Penetration Depth of Anchors in Sandy Bottom

Figure 3.11 illustrates the penetration depths for different types of anchors in relation to ship weight for bulk carriers and tankers. Figure 3.12 illustrates the same factors for general cargo and containerships.

3.3.3 SABOTAGE/CUT BY MAN

Some failures in the past have occured because of this hazard but for the present cable under study the outer armor is expected to be so strong that it would take a very deliberate work crew using underwater cutting and burning tools plus demolitions to sever this cable and cause failure.

3.3.4 CABLE MATERIAL FAILURE

a) Kink and Twist - Kinks start as loops of cable wound on themselves. When the loops are pulled tight, armor wires and conductors are permanently bent, thus severly damaging the cable at the kinks. Shorts or open circuits are likely to occur at the point of kinks.

For a twist or loop to develop in a tensioned cable two conditions must prevail. The cable must turn on itself, thus storing torsional energy, and the tension must be released. Most cables, with the exception of those properly torque-balanced, will turn when free ended. During lowering, if the payout rate is such that the speed of the cable exceeds the laydown rate then the cable will be in a slack loop, probably full of kinks. When on station with the winch stopped, ship roll will result in cable up and down motions. If the rate of fall of the cable is larger than cable laydown, the cable will again be slack.

b) Vanished Core - Not within scope of this study.

c) Repeater Failure - Since there are no repeaters of power cables, this item is not within the scope of this study.

d) Armor/Sheath Failure - Corrosion is one of the most obvious causes of deterioration and armor/sheath failure. It is easily detected but it effects are not always recognized. The loss of metallic cross section and resulting reduction of strength are the best known effects of corrosion.

3.3.5 SOIL THERMAL RESISTIVITY

Soils are composed of disintegrated rock particles, water, air and organic materials. In general, the thermal resistivity of these material components are considered to be that shown in Table 3.2.

Table 3.2 Soil Thermal Resistivity

Material	Thermal Resistivity* (°C-cm/Watt)
Quartz, average	11
Granite	25 - 58
Limestone	45
Sandstone	58
Water	165
Mica	170
Organic Material	400 (wet)
	700 (dry)
Air	4,000

It is obvious that the unit volume of soil should contain the maximum amount of rock particles and the minimum amount of air in the void to have the minimum thermal resistivity value. Since the soil can not be compacted to zero void, it is better to have the void filled with water rather than filled with air, providing that the water stays in the void permanently. Therefore, the thermal resistivity of a certain soil depends upon its density and water content. Figure 3.13 depicts the variation of the thermal resistivity of sand with respect to the water content. It indicates that the resistivity value increases as the water content decreases.

Field experience has shown that the thermal resistivity varies over a wide range for different parts of the country, and can even vary over a considerable range on a single cable route. Table 3.3 taken from reference 3 tabulates the average values of the field test data for 25 different soils encountered in the underground power cable installation.

* The thermal resistivity unit is defined as the number of centigrade degrees of temperature drop through a cube of 1 centimeter sides, through which heat is flowing at the rate of 1 watt, i.e., 1 joule per second. It is designated by the Greek letter ρ.

Table 3.3 Summary of Soil Thermal Resistivity Values

SOIL TYPE	NO. OF TESTS	THERMAL RESISTIVITY °C-cm/Watt Over-all Average
Fly Ash	7	212.9
Cinder-Ash Fill	76	191.3
Fill Dirt	81	95.1
Industrial Waste Fill	24	84.0
Loam	6	144.6
Clay Loam	25	126.4
Sandy Loam	63	78.2
Clay	801	54.9
Silty Clay	7	67.0
Sandy Clay	329	53.1
Silt	6	72.7
Sandy Silt	55	56.8
Sand	402	63.2
Clayed Sand	37	64.5
Silty Sand	4	113.6
Fine Sand	392	85.3
Coarse Sand	200	58.3
Gravelly Sand	2	111.1
Gravel	9	65.6
Clay Gravel	2	59.0
Rubble	2	80.0
Serpentine Rock	3	83.5
Quartz	32	75.8
Sand Stone	8	58.3
Shale	17	36.9

The hazard from soil thermal resistivity occurs when heat is transmitted from the buried power cable into the adjacent soil and this in turn can cause failure. It is not possible to discuss this hazard further until more detailed site and power cable characteristics are known.

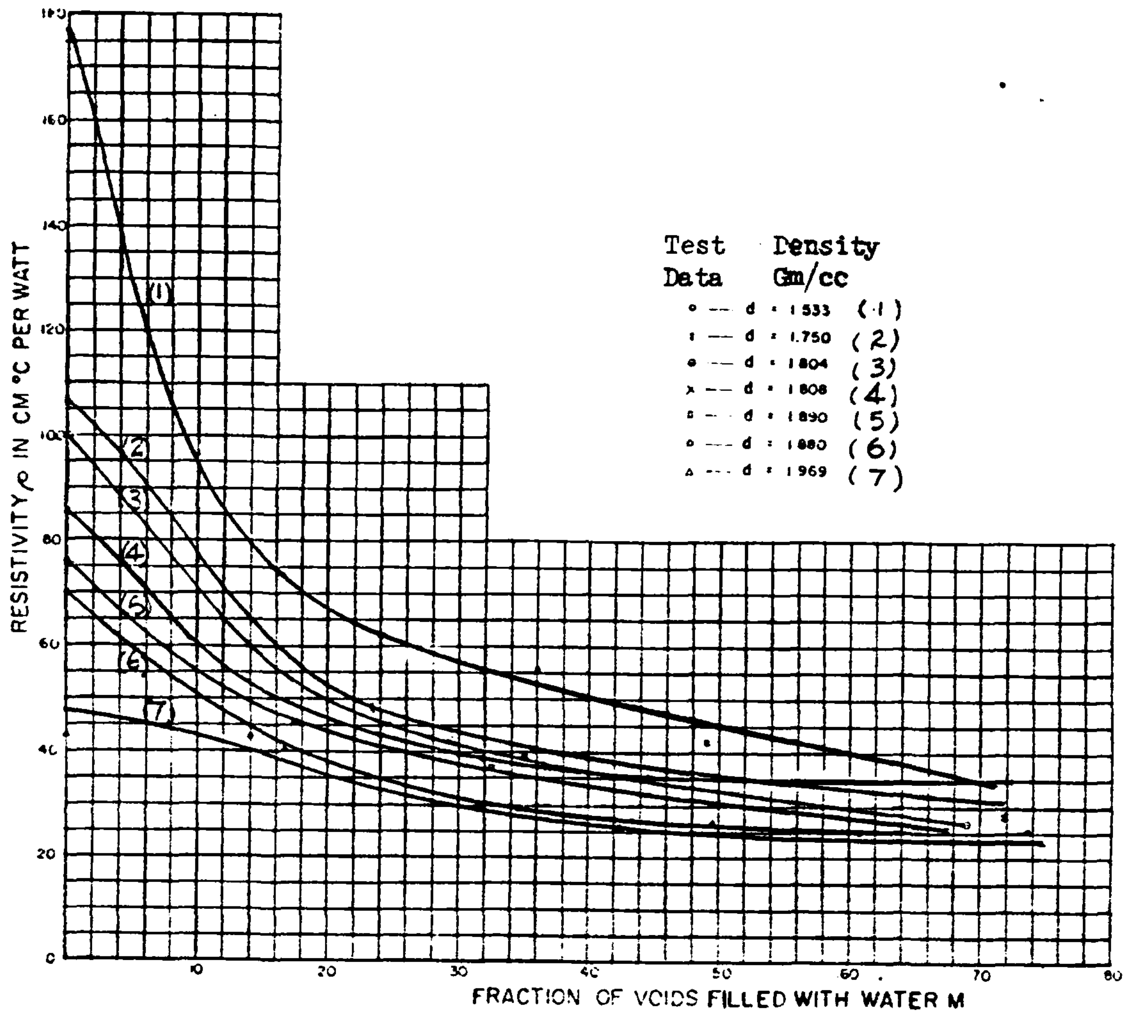


Figure 3.13 Variation of Thermal Resistivity

Of Sand with Respect to Water Content (Ref. 3)

CHAPTER 4. SUBMARINE CABLE FAILURE RECORDS & ANALYSIS

4.1 FAILURE RECORDS

A summary of a survey taken between 1956 and 1980 and reporting 85 faults by type of various submarine power cables in 12 submarine crossings is presented in Table 4.1. Two-thirds of these reported faults were externally caused, mainly by mechanical impact (trawlboards, anchors, etc.). Of the one-third internally caused faults roughly half of these were due to repair joints.* However, there is a great deal of variability between the different cables; two of the 12 crossings account for 12 of the 13 faults.

These power cables, as well as other cables and pipelines, are frequently buried over portions of their route, mainly near the shore with typical covers of only 2-3 feet. To date, no incidents of externally caused cable faults have been reported with buried power cables. The Japanese, however, have reported eight incidents of externally caused damage to buried communications cables in the past eight years. Continued and current information is needed regarding cable protection by burial.

4.1.1 AT&T RECORDS

The Long Lines Division of AT&T has reported that their six Trans-Atlantic Telephone (TAT) cables have experienced a total of 56 externally caused faults during a five-year period between 1975 through 1979. Of these, 54 were the result of trawlers, one was cuased by a clam dredge, and the other one was caused by corrosion (Ref. 33).

The distribution of these cable faults by water depth is shown in the following histogram, Figure 4.1.

* Ropes and data cables have splices; power cables have joints. Splices not installed at the factory are generally termed repair joints.

Crossing Ref No.	Location	Voltage (kV)	Power (MVA)	No. X Length (km)	Maximum Water Depth (m)	Year Installed	Total No. of Faults	Source of Fault: External: Mechanical	External: Other	Internal: Repair Joint	Internal: Other	Unknown
1	Vancouver Island B.C. Mainland	138 AC	120	5x31.1 2x31.1	102	1956 1958	3	2	1[a]			
2	Channel France-England	100 DC	160	4x65	60	1961	27	19		5	2[b]	1
3	Sweden-Denmark (Kontiskan)	250 DC	250	2x60		1964	26	12		7	7[c]	
4	Denmark (Kontiskan)	250 DC	250	2x25 1x25		1964 1970	8 0	2			6[d]	
5	New Zealand (North-South Island)	250 DC	600	3x38.6	250	1965	1			1		
6	Vancouver Island B.C. Mainland	260 DC	336 360	3x33 2x33	190	1969 1974	2 0	2 0				
7	Long Island Connecticut	138 AC	150	7x44	90	1969	12	9	3[e]			
8	Skarerrak Norway-Denmark	250 DC	500	1x127 1x127	550	1976 1977	2 0	2				
9	Prince Edward I New Brunswick	138 AC	100	2x(3x21.5)	20	1977	1		1[f]			
10	Norway - Various	145 AC		3x15		Various	2	2				
11	Norway - Oslo Fjord	300 AC		3x1.7		1959	1	1				
12	Norway - Oslo Fjord	420 AC		6x2.5		1975	0					
	TOTAL NUMBER OF FAULTS						85	51	5	13	15	1
	PERCENTAGE OF EACH TYPE OF FAULT						100	60	6	15	18	1
	PERCENTAGE BY MAJOR FAULT SOURCE						100	66		33		1

a - earthquake b - 1 - insulation; 1 - lead sheath; c - 1 - lead sheath; 6 - factory splice d - lead sheath
e - corrosion f - lightning

Table 4.1 Experience with Large Submarine Cable Crossings

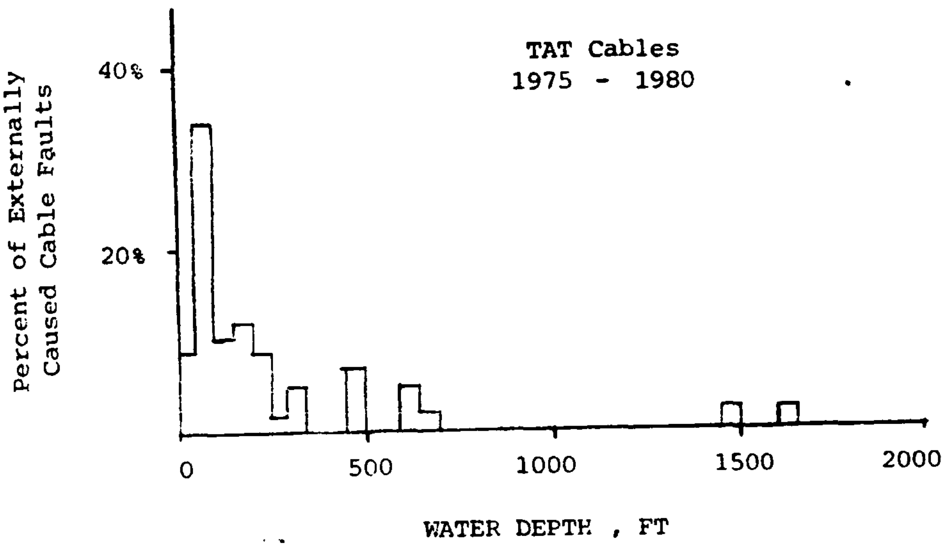


Figure 4.1 Histogram of Cable Failures

Over half of the incidents occurred in water depths of less than 150 ft. (46 m) and 89 percent were in depths of less than 500 ft. (152 m). The deepest incident of trawler damage was 1488 ft. (454 m) and the one incident of corrosion was at a depth of 1638 ft. (499 m). It is clearly evident that the preponderance of incidents occur in shallow or coastal waters but that some incidents also occur at deeper depths, and these cannot be ignored.

4.1.2 JAPANESE RECORDS

The Japanese have reported similar experiences with submarine communications cables (Refer to Table 4.2 for a tabulation of Failures during 1971 through 1975). During the 10 year period from 1967 through 1976, 483 incidents were reported. Eighty-six percent of the incidents were in water depths of 164 ft. (50 m) or less, and 98 percent were in water depth of 656 ft. (200 m) or less. Fishing, ships, and other artificial causes accounted for 67 percent of the incidents. Corrosion, chafing and other natural causes accounted for

19 percent and 14 percent were termed miscellaneous or unknown.

Table 4.2 Number of Cable Failures in Japanese Waters

Depth \ Year	1971	1972	1973	1974	1975	Total	%
Less Than 10 m	19	21	25	12	13	90	42
10 m to 20 m	3	7	13	4	4	31	15
20 m to 30 m	3	5	5	4	3	20	9
30 m to 40 m	4	5	2	3	7	21	10
40 m to 50 m	5	11	2	3	-	21	10
50 m to 100 m	2	3	9	2	5	21	10
100 m to 200 m	1	2	-	2	-	5	2
200 m to 500 m	-	1	-	1	1	3	1
More Than 500 m	-	1	-	-	-	1	1
Total	37	56	56	31	33	213	100

4.1.3 WORLD SEA RECORDS

The data concerning a total of 1,061 submarine cable faults or failures were collected and analyzed. The data covers a time period of 101 years (1879 to 1980) and geographically, the Mediterranean Sea, Gulf of Cadiz, North Atlantic, Coast of Alaska, East Coast of Asia, Southeast of Asia and Indian Ocean areas. Appendix A lists all the historical data of submarine cable faults. Table 4.3 tabulated these faults in total numbers by categories of failure - causes as discussed in Chapter 3. A probability distribution of

these failures is also given. It indicates that approximately one-half of the failures were caused by chafe and corrosion and one-quarter by trawler/clam dredge.

Table 4.3 Submarine Cable Failures Due to External Hazards

HAZARD	Recorded Failure	Unrecovered Failure	Total No. Failure	Probability Distribution (%)
1. Chafe & Corrosion	448	59	507	52
2. Trawler/Clam Dredge	213	28	241	24
3. Ship Anchor	70	9	79	8
4. Submarine Landslide	48	6	54	5
5. Earthquake	40	5	45	5
6. Sabotage/Cut by Man	22	3	25	3
7. Soil Thermal Conductivity	2	0	2	0
8. Miscellaneous	27	4	31	3
TOTAL	870	114	984	100

There were 77 additional failures due to cable failure, namely, kink and twist, vanished core, repeater failure, and armor/sheath failure.

* Miscellaneous includes wind storm, brushwood, falling rock, teredo, cable suspended over rock, grapnels hooked in clay, etc.

CHAPTER 5. THREAT DEFINITION AND PROTECTION REQUIREMENTS

5.1 THREAT DEFINITION

OTEC cables laid on the seafloor at the four sites selected are subject to failure and to the incapacity of supplying power to shore because they are threatened by chafing of the outer jacket or armor, corrosion of the outer armor and strain members, which are usually of galvanized steel, and breaking, all of which cause the electrical conductors to cease functioning.

Chafing occurs when the cable is moved across a hard bottom or when soil particles move across the cable. Cables are moved back and forth across a hard bottom by water currents and wave actions when they are not buried or not anchored in position. Chafing can also occur when an anchor dragging in the bottom or a grapnel hook at the bottom is snagged on a cable and moved along its length. Chafing of an outer protective jacket exposes the steel strain members to sea water and allows corrosion to take place. Corrosion can also occur through the fouling that occurs when cables are attacked biologically by marine organisms. Breakage of a cable can occur when a cable has had extensive chafing and corrosion so that it no longer has any tensile strength or when the extent of chafing and corrosion allows the main conductor to deteriorate. A cable under tension when suspended across two rocky peaks is subject to breaking when the tension becomes greater than the capacity of the cable to withstand such load. Dragging anchors and grapnel hooks snagged on a cable can induce a breaking load on a cable. Trawling operations with the use of otter boards or trawls on the seafloor can cause snagging of a cable and consequent breakage. The initial laying of a cable or its subsequent raising for repair are also causes of breakage through kinking and excessive tension. Landslides and seismic movements can produce sufficient tensions to

cause breakage.

5.2 PROTECTION REQUIREMENTS

The laying process and operation is the first action to take to insure proper protection for the cable by producing a cable on the seafloor that is in more or less perfect condition, free from kinks, excessive tensions and damage due to the laying process. For the inshore lengths of cable runs out to a depth of 400 to 500 fathoms some protective method is required for the cable at all four sites for here there is the possibility and probability of chafing, corrosion and breakage due to currents, wave action, ship anchor dragging and trawler action. For the outshore lengths of cable runs from a depth of 400 to 500 fathoms to the plant site the probability of cable failure due to the above causes are so minimal that laying the cable without protection seems very reasonable.

The best method of protection is of course burial to a sufficient depth where the probability of a snagging anchor becomes almost nil. Burial of course means digging a trench and refilling after the cable is laid. Sometimes in softer soils on the seafloor cables can bury themselves through current and wave action. Sometimes where the seafloor is so hard that trenching becomes impractical because of construction difficulties or excessive cost, covering the cable under these conditions with bagged sand, riprap, bagged concrete, poured concrete, or mattresses are feasible methods.

Anchoring a cable to a hard bottom is a means of protection against chafing due to cable movements where the hazards of trawling and anchor dragging can be avoided by stopping activities on the water surface.

Landslides are an occurrence for which it is almost impossible to provide

protection. The solution here would be to avoid areas prone to landslide activity by a thorough study of the seafloor soil conditions. It is also impossible to protect against earthquakes except to relocate if actual faults are found.

5.3 PROBABILITY OF HAZARDS

The probability distribution of the external hazards discussed in Chapters 3 and 4 are shown graphically in Figure 5-1. Data on the probability of occurence of these external hazards within 100 fathom water depth intervals were analyzed and are shown graphically in this chapter (See Figures 5-2 through 5-11). For instance, the probability distribution and the commulative probability for chafe and corrosion are shown on Figures 5-2 and 5-3. From Figure 5-2 it can be seen that approximately 40% of the chafe and corrosion-caused faults occur between 0 and 50 fathoms. From Figure 5-3, if a 90% probability of non-occurence of a fault from a chafe and corrosion is desired then it is necessary to go to a water depth greater than 450 fathoms (2700 ft.). Similarly, the probabilities for hazard failure by trawler/clam dredge, ship anchor, submarine landslide, and earthquake are shown in Figures 5-4 through 5-11. From these figures, the depths needed at which 90% of the probability of hazard damage would be eliminated is shown in Table 5-1. The distances from shore to eliminate 90% of the probability of damage from the hazards is shown in Table 5.2.

TABLE 5-1

Hazard	Depth to Eliminate 90% Probability of Damage
Ship Anchor Dragging	200 Fathoms
Trawler/Clam Dredging	250 Fathoms
Chafe and Corrosion	450 Fathoms

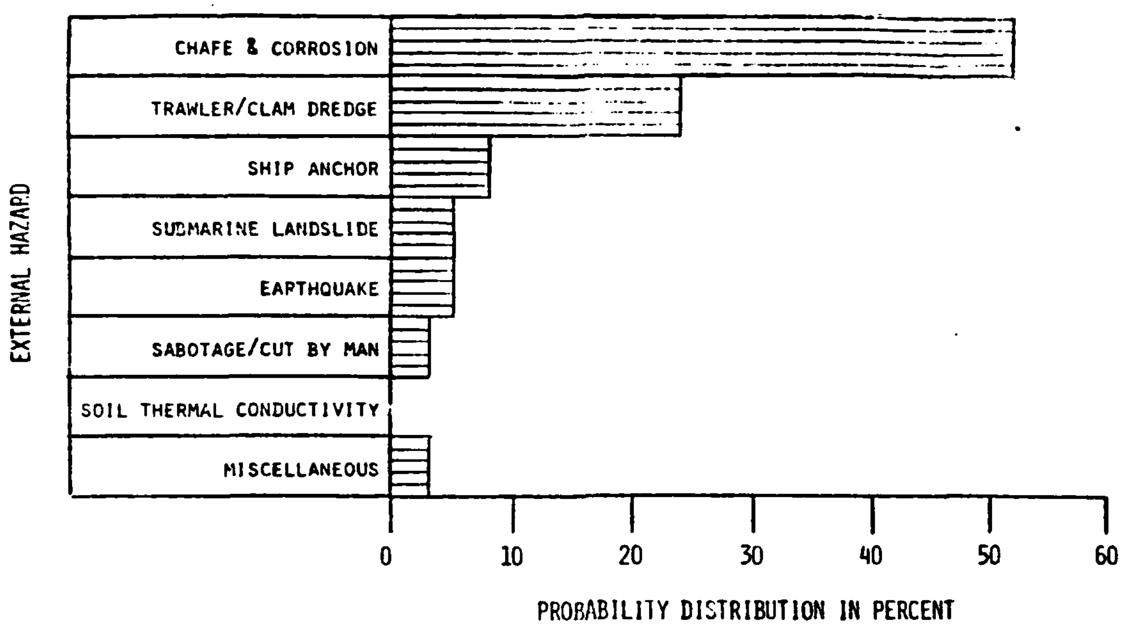


FIGURE 5.1 SUBMARINE CABLE FAILURES DUE TO EXTERNAL HAZARDS

TABLE 5-2

Site	Hazard	Distance From Shore (in nautical miles)
Kahe Point,	Ship Anchor Dragging	1.1
Oahu, Hawaii	Trawler/Clam Dredging	1.6
	Chafe and Corrosion	2.5
Punta Yeguas,	Ship Anchor Dragging	1.0
Puerto Rico	Trawler/Clam Dredging	1.1
	Chafe and Corrosion	1.3
Cabras Island,	Ship Anchor Dragging	0.3
Guam	Trawler/Clam Dredging	0.6
	Chafe and Corrosion	1.1
Tampa, Florida	Ship Anchor Dragging	98.0
Gulf of Mexico	Trawler/Clam Dredging	120.0
	Chafe and Corrosion	128.0

These values are depicted on Figures 5-12 through 5-15. The long distances at Tampa are the result of the shallow, wide shelf.

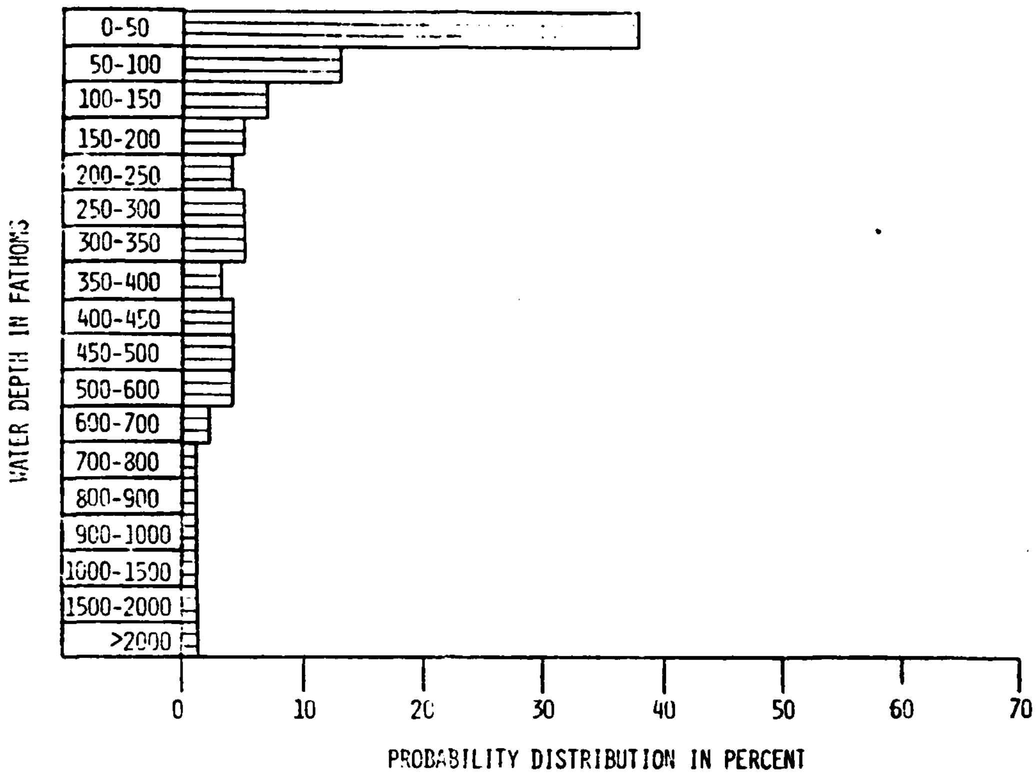


FIGURE 5.2 CHAFE & CORROSION

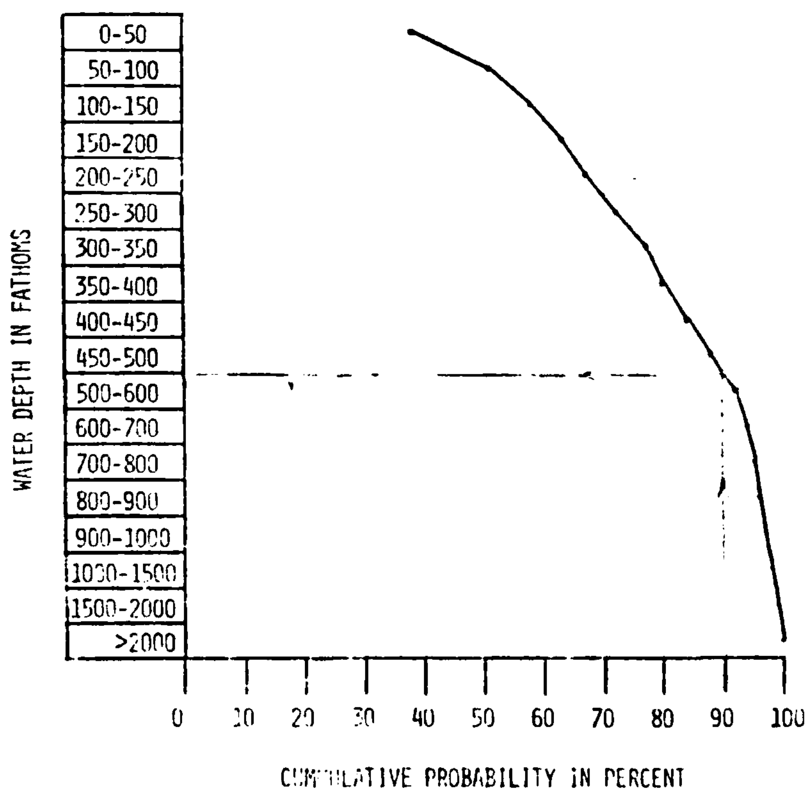


FIGURE 5.3 CHAFE & CORROSION

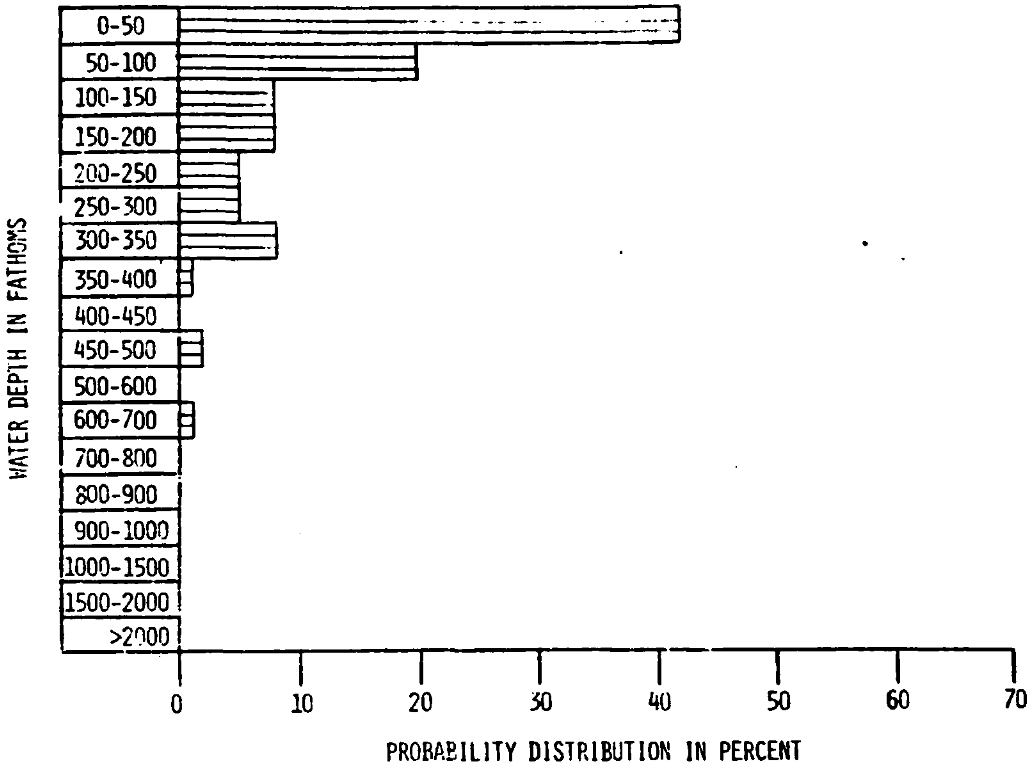


FIGURE 5.4 TRAWLER/CLAM DREDGE

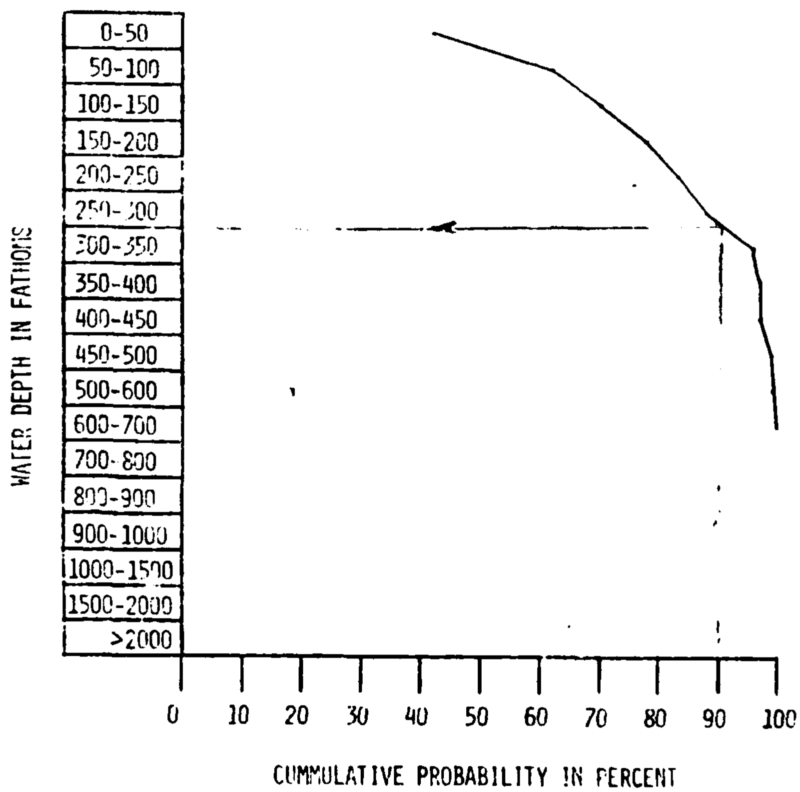


FIGURE 5.5 TRAWLER/CLAM DREDGE

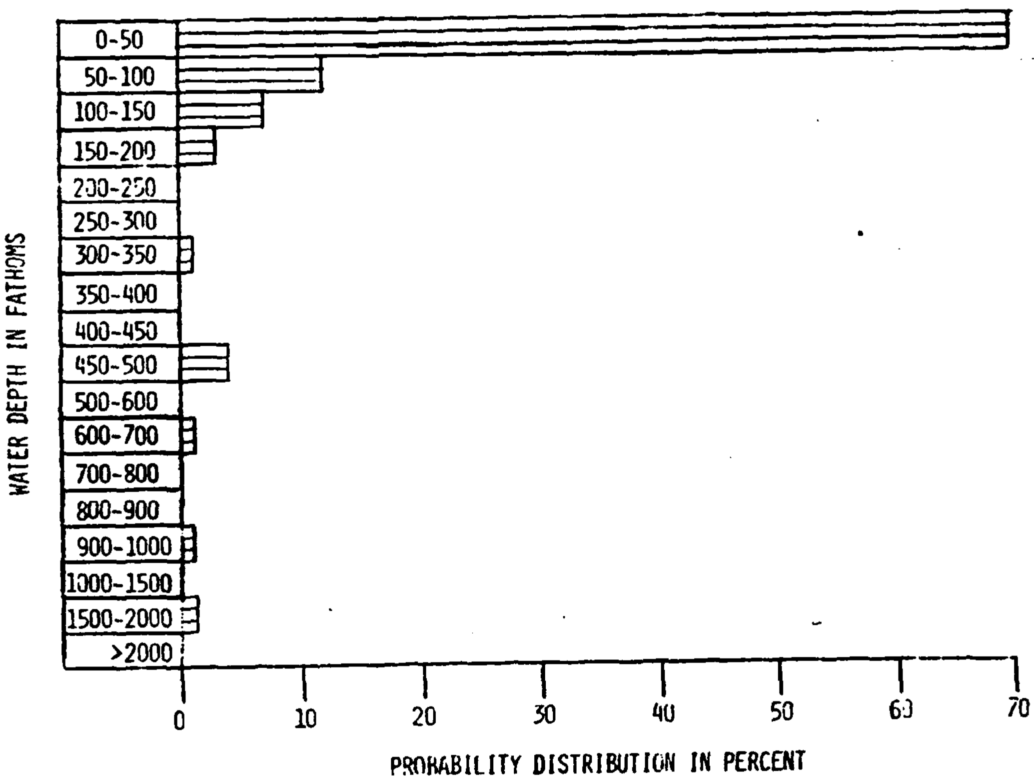


FIGURE 5.6 SHIP ANCHOR

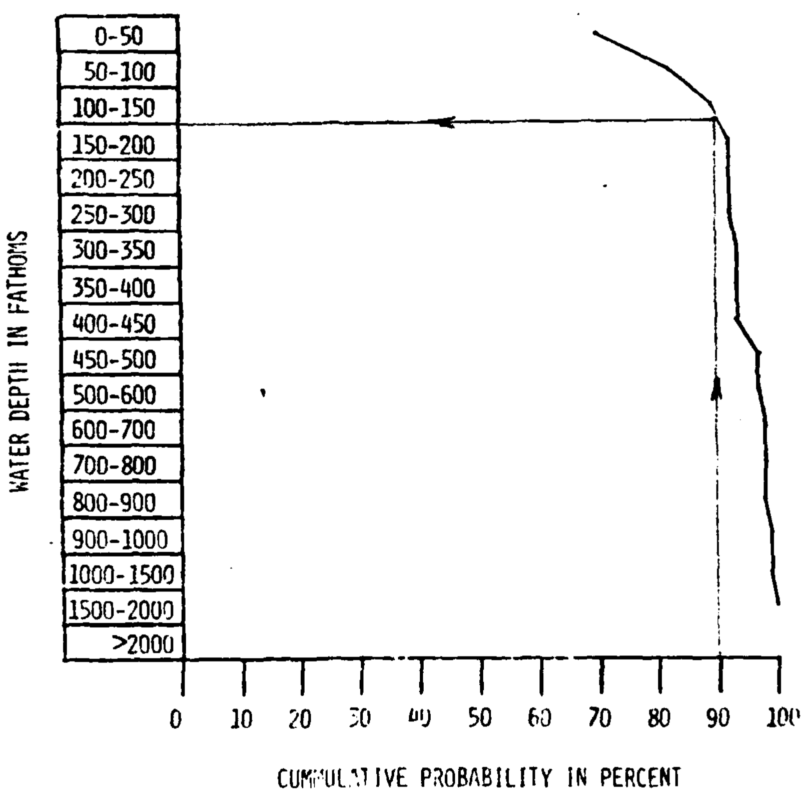


FIGURE 5.7 SHIP ANCHOR

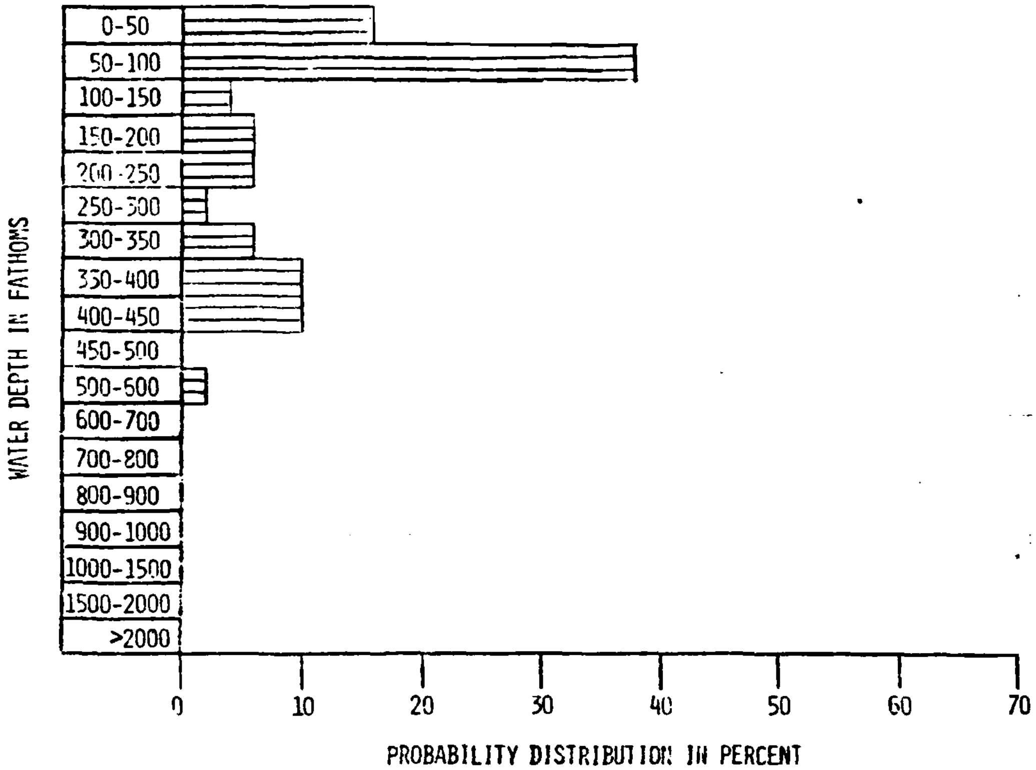


FIGURE 5.8 SUBMARINE LANDSLIDE

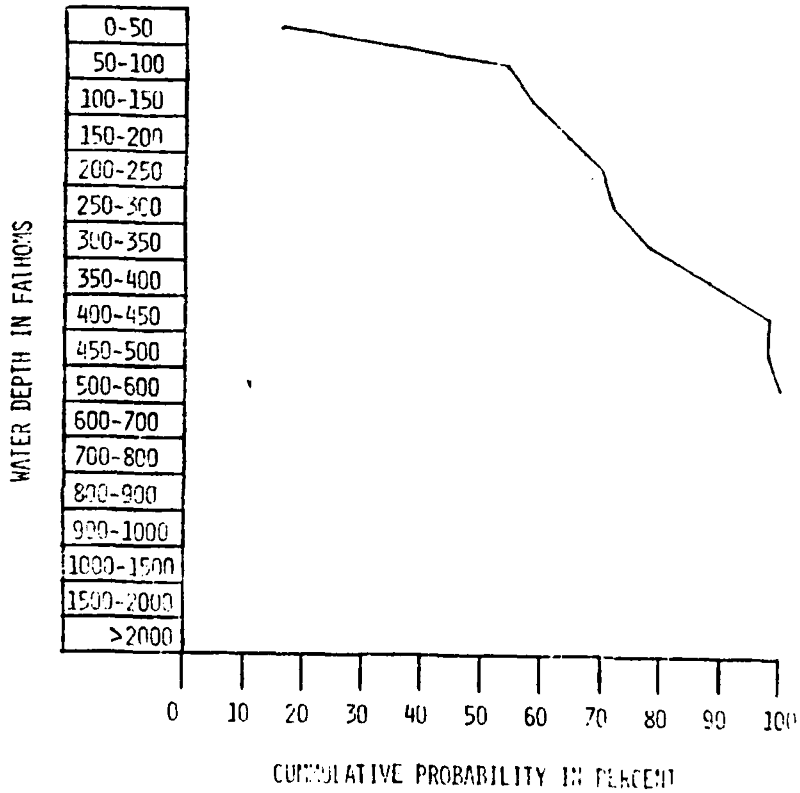


FIGURE 5.9 SUBMARINE LANDSLIDE

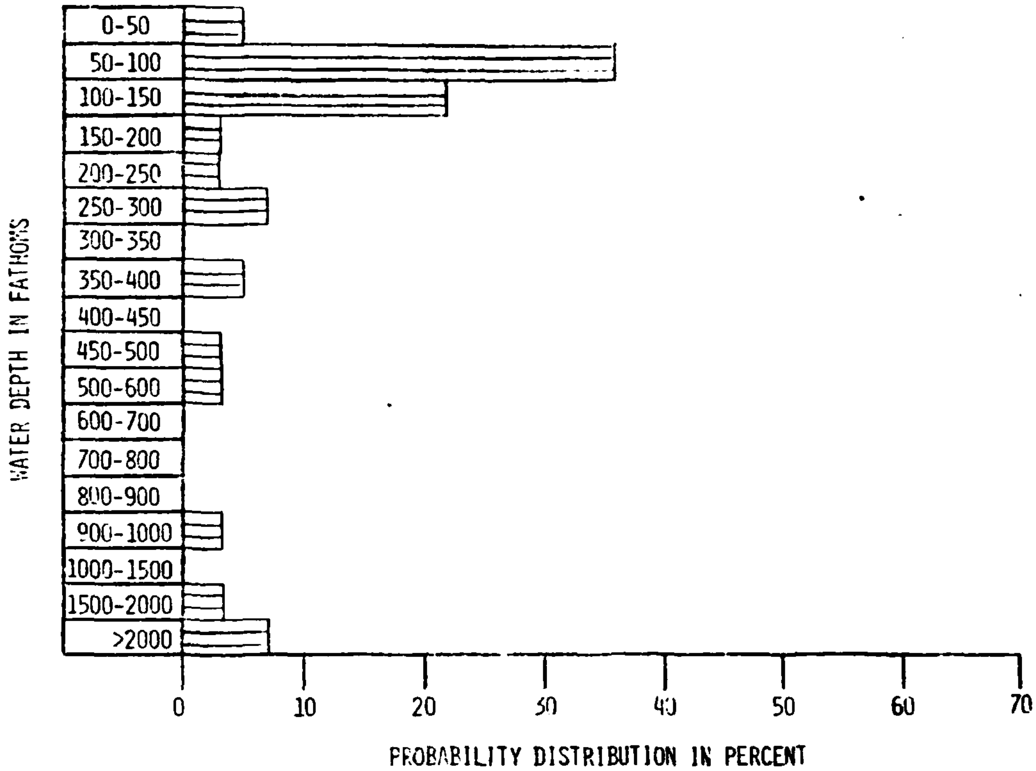


FIGURE 5.10 EARTHQUAKES

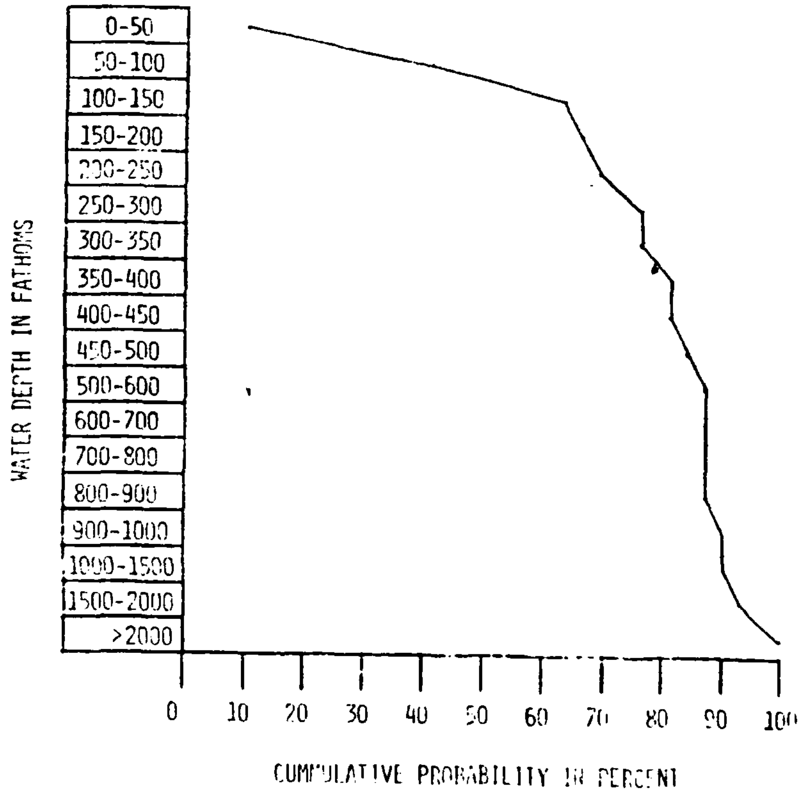
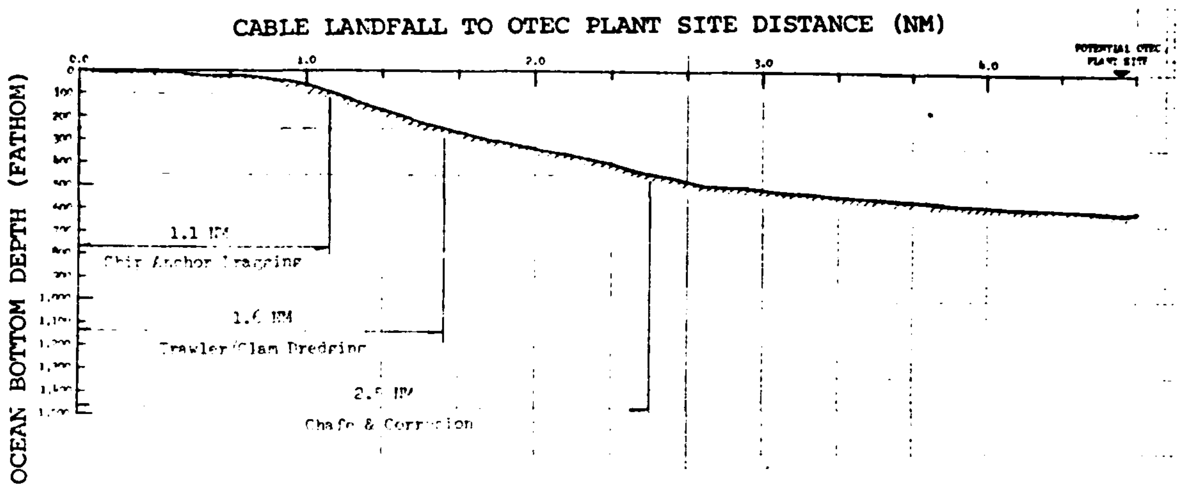
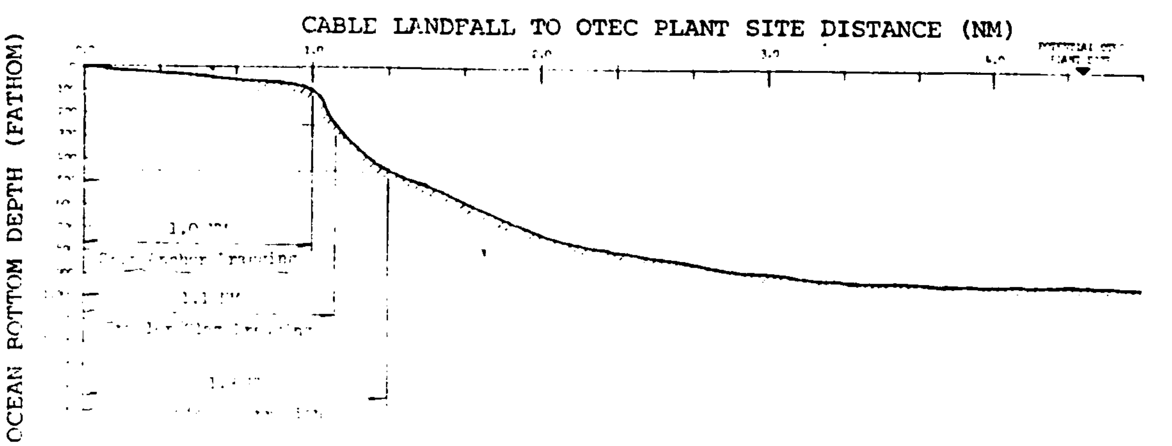


FIGURE 5.11 EARTHQUAKES



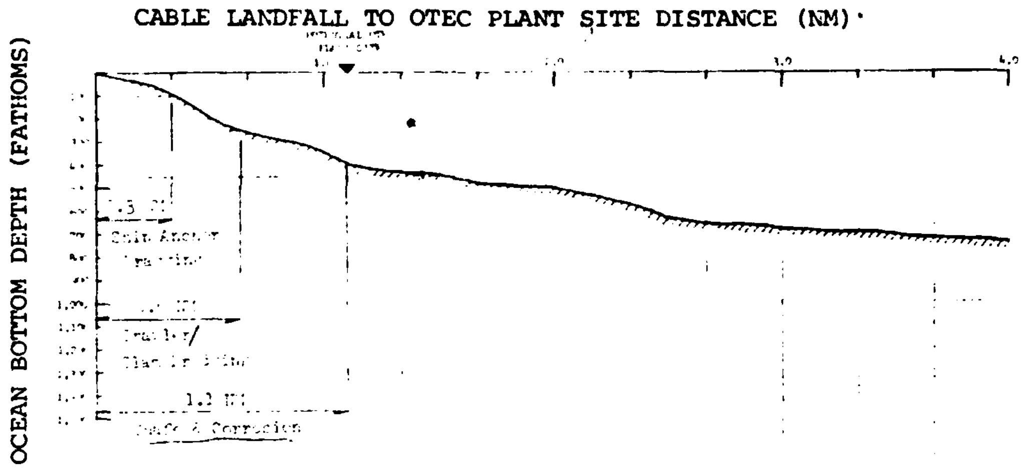
Required Distance From Shore Along OTEC Bottom Cable Route
To Eliminate 90% Probability of Damage

Figure 5.12 Kahe Point, Oahu, Hawaii



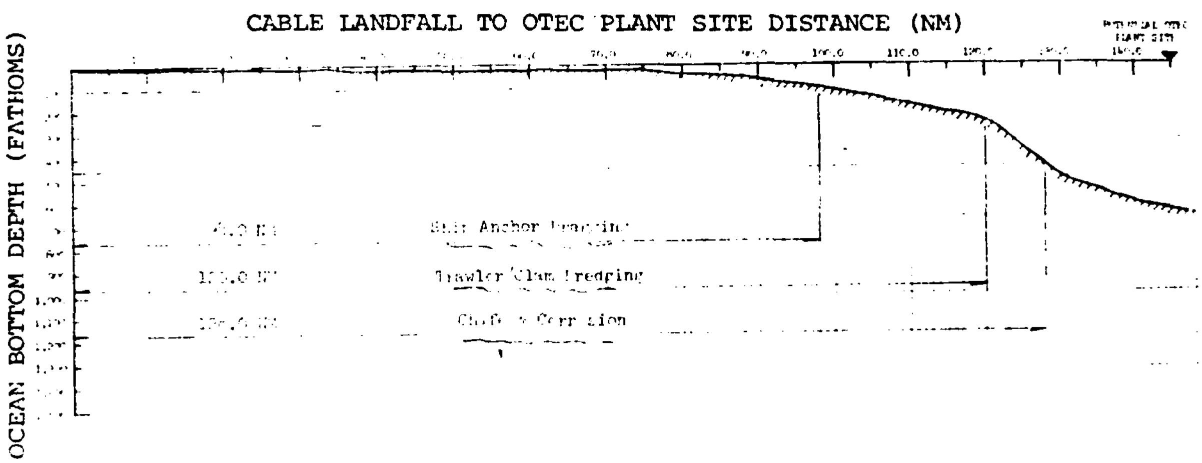
Required Distance From Shore Along OTEC Bottom Cable Route
To Eliminate 90% Probability of Damage

Figure 5.13 Punta Yeguas, Puerto Rico



Required Distance From Shore Along OTEC Bottom Cable Route
To Eliminate 90% Probability of Damage

Figure 5.14 Cabras Island, Guam



Required Distance From Shore Along OTEC Bottom Cable Route
To Eliminate 90% Probability of Damage

Figure 5.15 West Coast of Tampa, Florida, Gulf of Mexico

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. Based on the study of the modes and causes of cable failures and the study of the environmental and man-made hazards together with their probability at each of the four OTEC sites it is concluded that it is possible to assure the life and reliability of the OTEC submarine power cables. This is accomplished by using the modern techniques, tools and procedures of burial immobilization or stabilization for the cables for their installation. Modern techniques, tools and procedures are also available for maintenance and repair. Cable protection provided during installation is considered necessary starting out from shore to the point where the risk of encountering the hazards are so minimal that they can be tolerated. These points outshore have been selected on the basis of their depths of water outshore of which the probabilities of a hazard occuring would be reduced to ten percent. From these points outshore it is concluded that OTEC cables can be laid directly on the seafloor without protection.

2. For 3 proposed OTEC sites, namely Hawaii, Puerto Rico and Guam, a 90% chance of avoiding hazards of chafing, corrosion, anchors, and trawling can be achieved by using the proper protection techniques over a maximum of 2 nautical miles from shore. At the Tampa, Florida site the protection of over 100 nautical miles is required. Rerouting ship traffic from crossing over the cables with a view of avoiding hazards such as anchors and trawling is not a feasible solution at the four sites with a possible exception of Guam where the length of cable line is only 1.1 nautical miles from shore.

6.2 RECOMMENDATIONS

1. The data given hereinbefore for each of the sites concerning the

lengths of cables from the shore needing protection are considered to be merely "ball park" estimates. A more detailed design process would be in order to define more precisely the type of protection to be adopted and to define the required distance more precisely. Such a detailed process would include a site survey, more precise computations concerning wave characteristics and a hydrodynamic analysis of the forces acting on the cables on the bottom.

APPENDIX A

SUBMARINE CABLE FAILURE DATA STUDIED

Table	Title
A.1	North Atlantic Ocean Region Submarine Cables
A.2	Alaskan Waterways Submarine Cables
A.3	Gulf of Alaska Submarine Cables
A.4	Puget Sound Submarine Cables
A.5	Indian Ocean Region Submarine Cables
A.6	Mediterranean-Gulf of Corinth Region Submarine Cables
A.7	Gulf of Cadiz Region(Carcavelos-Gibraltar 1) Submarine Cables
A.8	Gulf of Cadiz Region(Carcavelos-Gibraltar 2) Submarine Cables
A.9	Gulf of Cadiz Region(Carcavelos-Gibraltar 4) Submarine Cables
A.10	Gulf of Cadiz Region(Gibraltar-Casablanca) Submarine Cables
A.11	Gulf of Cadiz Region(Porthcurno-Gibraltar 3) Submarine Cables
A.12	Gulf of Cadiz Region(Porthcurno-Gibraltar 4) Submarine Cables
A.13	Gulf of Cadiz Region(Vigo-Gibraltar) Submarine Cables
A.14	Gulf of Cadiz Region(Horta-Malaga) Submarine Cables
A.15	Gulf of Cadiz Region(Las Palmas-Malaga) Submarine Cables
A.16	Gulf of Cadiz Region(Lisbon-Malaga) Submarine Cables
A.17	U.S.Air Force Cable Systems
A.18	Pacific and Far East Pacific Submarine Cables
A.19	Submarine Power Transmission Cable Failure Record

Table A.1 North Atlantic Ocean Region Submarine Cables (Ref. 33)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Tuckerton, New Jersey	25 XI '75	29 XI '75	73	Trawler
	11 XII '75	17 XII '75	134	Trawler
	19 IV '76	23 IV '76	73	Trawler
	21 V '76	30 V '76	98	Trawler
	25 V '76	28 V '76	145	Trawler
	3 X '76	8 X '76	100	Trawler
	12 X '76	19 X '76	16	Trawler
	1 II '77	13 II '77	20	Trawler
	28 VII '77	10 VIII '77	69	Trawler
	4 XII '77	9 XII '77	20	Trawler
	27 I '79	10 II '79	70	Trawler
	15 II '79	20 II '79	77	Trawler
	15 II '79	26 II '79	79	Trawler
	9 III '79	13 III '79	74	Trawler
	10 IV '79	17 IV '79	240	Trawler
	7 VIII '79	16 VIII '79	15	Clam dredge
Syney Mines, Nova Scotia	16 X '76	26 X '76	230	Trawler
Cabot Strait, Canada	7 III '77	15 III '77	239	Trawler
Clarenville, Newfoundland	13 VIII '75	19 VIII '75	170	Trawler
	25 II '76	11 IV '76	190	Trawler
	19 III '76	24 IV '76	189	Trawler
	27 II '77	6 III '77	220	Trawler
	26 VI '77	28 VI '77	226	Trawler
	27 VII '77	12 VIII '77	650	Trawler
	28 VII '77	9 VIII '77	[illegible]	Trawler
	31 VII '77	7 VIII '77	665	Trawler
	15 X '77	30 X '77	[illegible]70	Trawler
	1 II '78	11 II '78	342	Trawler
	5 III '78	14 III '78	470	Trawler
	[illegible] III '78	24 III '78	47[illegible]	Trawler
	[illegible] III '78	31 III '78	4[illegible]8	Trawler
	1[illegible] V '78	23 V '78	313	Trawler
	[illegible] X '78	6 X '78	3[illegible]	Trawler
	[illegible] X '78	29 X '78	160	Trawler
	17 XI '78	Not repair'd	47[illegible]	Trawler

Table A.1 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Clarenville, Newfoundland	18 XI '78	22 XI '78	166	Trawler
	7 VII '79	9 VII '79	600	Trawler
Oban, Scotland	11 VII '75	17 VII '75	82	Trawler
	13 III '76	17 III '76	180	Trawler
	25 IV '76	27 IV '76	94	Trawler
	14 VIII '76	22 VIII '76	149	Trawler
	21 XI '76	3 XII '76	88	Trawler
	29 III '77	3 IV '77	79	Trawler
	11 IV '77	25 IV '77	113	Trawler
	2 XII '77	17 XII '77	130	Trawler
	1 III '78	4 III '78	98	Trawler
	31 III '78	4 IV '78	111	Trawler
Widemouth, England	29 VI '76	3 VII '76	81	Trawler
	30 IV '79	14 V '79	1638	Corrosion
	26 V '79	2 VI '79	85	Trawler
	26 IX '79	8 X '79	50	Trawler
Penmarch, France	31 VII '75	13 VIII '75	1488	Trawler
	29 VIII '75	6 IX '75	79	Trawler
	23 IX '75	30 IX '75	155	Trawler
	20 III '77	24 III '77	87	Trawler

Table A.2 Alaskan Waterways Submarine Cables (Ref. 9)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Approaches to Wrangell				
	19 XI '12	20 XI '12	69	Submarine Landslide
	6 VII '13	25 VII '13	20-68	Submarine Landslide
	6 VII '13	26 VII '13	73-83	Submarine Landslide
	4 X '15	18 X '15	93-96	Submarine Landslide
	21 X '18	28 X '18	70	Submarine Landslide
	29 VI '23	7 VII '23	10-68	Submarine Landslide
	27 IX '23	11 X '23	10-68	Submarine Landslide
	10 XII '25	17 XII '25	50-73	Submarine Landslide
	24 X '27	1 XI '27		Submarine Landslide
	21 VIII '47	30 VIII '47	60	Earthquake
	21 VIII '49	30 IX '49	70-83	Earthquake
	21 VIII '49	30 VIII '49		Earthquake
	9 VII '58		60	Earthquake
	9 VII '58		60	Break. Deeply buried in mud
Approaches to Skagway				
	9 VII '58		96-126	Earthquake
	24 X '27	8 XI '27	72	Submarine Landslide
	1 XII '56		46	70-75mph windstorm
	1 XII '56		50	70-75mph windstorm
	9 VII '58		50	Earthquake
	16 VI '52		50	Unknown
	13 VIII '24	19 X '24	46-57	Submarine Landslide
		28 VIII '20	63	Submarine Landslide
	5 II '06	12 II '06		Submarine Landslide
		19 II '47	60	Anchor hook
		20 VII '03	0-240	Cable badly kinked and bruised
	10 IX '27	23 IX '27	135	Submarine Landslide
		17 IX '40		Unable to find old cable, new one laid
	9 VII '58		100	Earthquake
	9 VII '58		80-150	Earthquake
	1 XI '4[illegible]	4 XI '[illegible]	1	Improper [illegible]

Table A.? (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Approaches to Valdez	4 II '08	29 II '08	79-129	Earthquake
	4 II '08	29 II '08	15-103	Earthquake
	11 IX '11	30 IX '11	98-115	Earthquake
	17 XII '13	23 XII '13		Anchor dragging
	10 IX '17	13 X '17		Anchor hook
	28 XI '20	10 XII '20	95	Earthquake
	28 XI '20	8 XII '20	100	Earthquake
	20 VIII '21	29 VIII '21	95	Submarine Landslide
		29 VII '22	95	Submarine Landslide
	23 II '25	6 III '25	76	Earthquake
	23 II '25	6 III '25	84	Earthquake

Table A.3 Gulf of Alaska Submarine Cables (Ref. 6)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Cape Ommaney to Middleton Island		26 IX '16	19-100	Hooked by fisherman's anchor
	29 IX '15	16 X '15	95-105	Chafe on rocky bottom
	21 III '08	11 IV '08	1030-1118	Chafed and bruised
	8 X '14	12 X '14	732-925	Imperfact insulation
		9 V '15	948-970	Core protruding between armor wires
		17 XI '21	118-172	Chafing on bottom
		10 XI '09	27-88	Cable can not stand the strain from heavy swell
	2 X '07	7 X '07	16-180	Earthquake
		2 VI '16	118-198	Fishing vessel's anchor
	2 XII '13	15 XII '13	55-122	Chafing on rocky bottom
	3 V '17	26 V '17	348-970	Fishing boat anchor
		20 II '21	714-742	Cable in very poor condition,broke while grappling
	11 V '16	1 VI '16	104-105	Fishing boat anchor
	24 XI '16	19 XII '16	200-790	Fishing vessel's anchor
	30 I '16	8 III '16	164-175	Fishing vessel's anchor
	1 VI '05	15 VI '05	959	Core weakness
	24 VI '10	28 VI '10	500-1008	Cable in poor condition
		20 X '14	120-150	Unknown
	6 X '21	19 XI '21	95-329	Chafe on bottom
	19 X '14	23 X '14	150	Hooked by a vessel's anchor
		12 VI '11	340	Submarine Landslide
		21 XI '21	60-106	Bad insulation
		26 VII '22	55-81	Unknown
		14 VIII '30	110	Unknown
	3 V '43	10 VI '43	300-2400	Foreign body imbedded in cable during manufacture,resulting in cable broke down

Table A.4 Puget Sound Submarine Cables (Ref. 6)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Port Jefferson to Foulweather Bluff		25 I '09	90	Hooked by anchor
		23 II '09	120	Poor insulation
	8 X '10	9 X '10	106	Unknown
		11 X '10	16	Chafe on bottom
	21 XI '10	24 XI '10	39	Light type chafing against rocky bottom
		6 III '12	54-62	Submarine landslide
		23 VIII '13	70	chafe on bottom
	30 VIII '14	7 IX '14	39	Cable cut by axe
	19 IX '15	27 IX '15	97-106	Chafe on bottom
	1 XII '16	27 XII '16	34	Chafe on rocky bottom
	9 II '18	12 II '18	67	Chafe on rocky bottom
		16 VIII '18	50-89	Cable in very poor condition
		11 III '19	93-148	Cable in very poor condition, broke while grappling
		31 VII '19	32 94	Cable in very poor condition
		2 VII '20	112-138	Inserted special intermediate type
		30 XII '21	50-80	Chafe on bottom
	26 V '24	25 I '25	88	Chafe on bottom
	27 VII '28	30 VII '28	98	Chafe on bottom
	1 VIII '47	2 III '47	93	Unknown

Table A.5 Indian Ocean Region Submarine Cables (Ref. 6)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
Mauritius - Seychelles	16 IX '98	30 IX '98	785-200	Cable broken sharply and showed no signs of chafe
	24 IX '06	8 X '06	896 -54	Break-ends needle pointed
	21 VI '14	4 XII '14	790 -70	Fault-perished joint
	25 III '17	20 V '19	275 -9	Fault-no data
		24 XII '24	1392 -115	Fault-not recovered
	28 XII '45	5 I '46	-146	Chafe and corrosion
	21 V '51	2 VI '51	173 -12	Break-corroded kink
		2 VII '58	543 -19	No data,renewal at shore end
Durban - Mauritius	24 II '28	17 IV '28		Break-seismic disturbance. The cable end had been sheared off flush.
	12 VII '54	12 IX '54	1776 - 1806	Break-bad corrosion
Mauritius-Rodriguez	14 IV '19	6 V '19	17 -15	Break-corrosion
	20 X '19	3 XI '19		Fault-anchor
	18 VII '25	21 VII '25	1164 -289	Fault-not recovered
	28 VI '25	18 VII '25	1164 -825	Break-chafe and corrosion
	29 X '26	8 XI '26	11 -8	Fault-no data
	7 IV '27	12 IV '27	330 -39	Break-chafe and corrosion
	28 I '29	18 I '29	1765 -915	Break-not recovered
	26 I '30	6 II '30	290 -29[illegible]	Submarine landslide
	17 VII '33	4 VIII '33	297 -305	Break-corrosion
	2 VIII '33	9 XI '33	830 -250	Break-corrosion
		10 X '36	52 -44	Renewal of bad cable
	[illegible] XI '39	10 XII '39	218 -3[illegible]	Fault-chafed
	[illegible] XI '39	18 XII '39	980 -308	Fault-chafed
	4 IX '40	24 IX '40	290 -[illegible]	Break-chafed and corroded
	23 IX '41	10 XI '41	51[illegible] -1000	Break-corrosion
	18 XII '41	27 XII '41	[illegible] -3[illegible]	Chafe and corrosion

Table A.5 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathoms)	Cause of Failure
Mauritius-Rodriguez	15 X '43	29 XI '43	270 -275	Break-chafe
	25 XI '43	2 XII '43	500 -295	Fault-unrecovered
	4 VIII '47	22 VIII '47	8	Break-corrosion
	23 VIII '47	28 VIII '47	1050 -820	Break-not recovered, end corroded unfit for use
	17 X '48	2 XII '48	290 -345	Chafe and corrosion
	24 XII '53	21 I '54	560 -1496	Break due to kink near splice
	14 XI '53	7 IV '55	2510-2148	Break-chafe
	23 V '55	15 VIII '55	2260-2420	Fault-unrecovered due to poor condition
	24 II '56	6 IV '56	1010-2400	Chafe and corrosion
	5 IV '56	9 IV '56	314 -292	Break-perished core
	7 IV '56	18 IV '56	2230-2280	Fault-unrecovered
	21 V '57	24 IV '57	34 -29	Fault-chafe and corrosion
	17 XI '57	12 IV '58	20 -1106	Break-unrecovered
Reunion-Mauritius	18 V '10	17 X '10	480 -38	Break-corrosion
	18 X '13	19 XI '13	485 -420	Break-submarine volcanic disturbance
	14 IX '15	22 X '15	93 -20	Break-corrosion
	22 VIII '16	23 V '19	1375-1115	Break-not recovered, cable in poor shape.
	23 V '19	26 V '19	850 -480	Corrosion
	28 V '19	1 VI '19	510 -8	Chafe
	1 XII '21	3 XII '21	600 -493	Corrosion
	27 XII '24	28 XII '24	38 -0	Corrosion
	10 VI '26	25 VI '26	630 -690	Twisted and corroded
	18 X '26	17 IV '27	1086-553	Chafe
	27 IV '27	17 XII '27	2350-2392	Break-submarine volcanic disturbance
	21 XI '30	27 II '31	590 -620	Break-at new splice
	27 II '31	12 III '31	1650-2190	Fault-not recovered
	5 IX '33	1 XII '33	297 -16	Break-not recovered
	6 II '34	7 VII '34	6 -54	Chafe and corrosion
	31 X '36	18 VI '37	677 -18	Chafe
	[illegible] VI '37	20 VI '38	[illegible]-2300	Corrosion
	30 VII '37	3 VIII '38	408 -640	Cable crushed and flattened

Table A.5 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
Reunion-Mauritius	21 XI '38	28 VII '39	943 -1180	Chafe and corrosion
	3 XII '43	10 XII '44	618	Corrosion
	11 IV '44	10 VI '44	325 -454	Break and faults, damaged by boulders sucked down by tidal waves
	20 XII '46	8 IX '47	583 -1026	Corrosion

Table A.6 Mediterranean-Gulf of Corinth Region Submarine Cables (Ref.7)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Gulf Entrance	19 II '12	24 II '12	40	Break-chafe and corrosion
	12 III '15	14 III '15	25	Chafe and corrosion
		1 II '20	22	Fault-unrecovered
	21 II '21	2 III '21	31	Chafe and corrosion
	17 VIII '27	18 VIII '27	46	corrosion
		2 VII '31	27	Unknown
	27 I '32	9 IX '32	29	Chafe and corrosion
	27 III '39	5 XII '39	30	Chafe and corrosion
	18 VIII '49	21 VIII '49		Cable cut by robbers
		5 IX '49	47	Perished core
	9 II '57		47	Corrosion
Western Gulf	25 VIII '89		37	Submarine landslide caused by earthquake
	22 IV '95	2 V '95	51	Chafe
	4 X '97	12 X '97	46	Submarine landslide
	I '18	21 II '18	43	Corrosion
	30 III '28	4 IV '28	55	Submarine landslide due to fresh water bottom depth current
Axial Canyon-Western Gulf	10 IX '02		104	Strong earthquake
	9 V '05	9 XII '05	202	Bad kink
	8 V '10	10 V '05	164	Corrosion
Seaward slope of Erineous River	19 IV '07	24 IV '07	150	Earthquake
	19 IV '07	24 XI '07	158	Earthquake
		2 VI '21	140	Cable deeply buried
	12 XI '07	14 XI '27	164	Submarine landslide
Seaward slope of Meganitis River	9 IX '88		300	Submarine landslide due to earthquake
		11 VII '09	300	Badly perished core
		3 III '30	[illegible]	Fault-teredo
	28 VII '37	5 VIII '37	[illegible]	Corrosion

Table A.6 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Off the Kratis and Krios Rivers	20 IX '88	25 IX '88	200	Cable snapped by heavy strain
	25 VIII '89		400	Submarine landslide due to earthquake
	30 V '09	11 VI '09	400	Earthquake
	28 VIII '13	30 VIII '13	398	Submarine landslide from Kratis River
	18 I '14	13 II '14	413	Submarine landslide
	26 VI '31	30 VI '31	443	Corrosion
	9 XII '35	20 XII '35	419	Chafe and tension
	19 IV '39	20 XI '39	420	Corrosion
	5 IX '49		412	Corrosion
Off the Avgo River	19 IX '10	6 X '10	398	Submarine landslide
	18 IX '10	27 IX '10	422	Submarine landslide
	18 XI '11	23 XI '11	200	Submarine landslide
		3 XI '13	400	Bad kink
	18 XII '20	27 XII '20	410	Buried by deposits from torrents
	5 I '23		210	Submarine landslide
	22 II '29	29 II '29	400	Buried by deposits from torrents
	9 XII '35	23 XII '35	352	Tension at the point of corrosion
Off the Dendron River	28 II '08	9 III '08	105	Jammed core
	14 V '08	15 VI '08	50	Submarine landslide
	29 IX '08	7 X '08	100	Submarine landslide
	14 II '14	15 III '14	420	Deeply buried in mud
	18 XII '20	23 XII '20	100	Buried by deposits from torrents
	18 XII '20	23 XII '20	400	Submarine landslide
	19 XII '35	19 XII '35	90	Submarine landslide due to strong gales
	30 XI '37	25 [illegible] '38	360	Corrosion at twist
Off the Sithas River	[illegible] I '04	9 I '04	275	Cable broken by heavy brushwood
	[illegible]8 VIII '09	[illegible] IX '09	300	Damaged due to falling mass
	[illegible] XII '14	7 [illegible] '1[illegible]	300	Submarine landslide

Table A.6 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Off the Sithas River	30 X '18	6 XI '18	340	Submarine landslide
	20 X '19	24 X '19	220	Submarine landslide
		14 XII '20	450	Corrosion
	9 XII '21	13 XII '21	50	Damaged by debris from torrents
	9 XII '21	14 XII '21	370	Submarine landslide
	27 III '39	8 XII '39	100	Chafe and corrosion
East of Sithas River	7 III '00	8 III '00	271	Corrosion and splice slipping
	22 IV '28	30 V '28	220	Submarine landslide
		22 VIII '35	300	Teredo
	27 III '39	6 XII '39	75-50	Perished core
	1 III '40		300	Corrosion

Table A.7 Gulf of Cadiz Region (Carcavelos-Gibraltar 1) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Failure	Water Depth @ Splices (Fathom)	Cause of Failure
South of Tarifa		XII '79		Break-chafe
		16 XI '81		Break-chafe
		2 III '82		Break-chafe and corrosion
		X '83		Teredo
		XI '84	390-330	Kink, twist and broken wires
		12 III '85		Corrosion
South of Cape St. Vinc		13 II '85		Fault-cable suspended over a rock
South of Tarifa	23 I '87	7 II '87		Break-no data
Northern Gulf		V '87	300-275	Corrosion
		V '87	570-700	Corrosion
		II '89	386	Fault-no data
	22 I '89	II '89	1100-650	Break-no data
		8 IV '91	56-33	Break-no data
Str. of Gibraltar		15 V '91	9	Chafe
Northern Gulf		19 VII '93	43	Chafe
		30 VII '93	35-38	Chafe
	28 VII '93	3 VIII '93	445-490	Fault at kink
	26 XI '93	30 XI '93		Chafe
	21 IV '94	27 IV '94	610-435	Cable buried in mud, broken by strain
		1 V '94		Fault at kink
		5 V '94		Teredo
Cape St. Vinc		23 V '95	480-428	Corrosion
Northern Gulf		31 XII '95	765-596	Teredo
		14 I '96	19-50	Chafe
		12 X '96	334-293	Corrosion
	20 X '96	14 XI '96	23	Chafe
	1 X '97	3 X '97	32	Chafe
	25 IX '97	2 X '97	18	Chafe
		18 VII '98		Fault at kink
	30 V '99	2 VI '99		Chafe
	27 VI '99	30 IX '99	75-110	Chafe and corrosion
		20 VIII '99	320-294	Teredo
		9 IX '00	45	Fault-no data
		18 X '00		Chafe and corrosion
		31 XII '00		Fault-no data
	26 XII '00	28 XII '00		Chafe

Table A.7 Gulf of Cadiz Region (Carcavelos-Gibraltar 1) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
South of Tarifa		XII '79		Break-chafe
		16 XI '81		Break-chafe
		2 III '82		Break-chafe and corrosion
		X '83		Teredo
		XI '84	390-330	Kink, twist and broken wires
		12 III '85		Corrosion
South of Cape St. Vinc		13 II '85		Fault-cable suspended over a rock
South of Tarifa	23 I '87	7 II '87		Break-no data
Northern Gulf		V '87	300-275	Corrosion
		V '87	570-700	Corrosion
		II '89	386	Fault-no data
	22 I '89	II '89	1100-650	Break-no data
Str. of Gibraltar		8 IV '91	56-33	Break-no data
Northern Gulf		15 V '91	9	Chafe
		19 VII '93	43	Chafe
		30 VII '93	35-38	Chafe
	28 VII '93	3 VIII '93	445-490	Fault at kink
	26 XI '93	30 XI '93		Chafe
	21 IV '94	27 IV '94	610-435	Cable buried in mud, broken by strain
		1 V '94		Fault at kink
		5 V '94		Teredo
Cape St. Vinc		23 V '95	480-428	Corrosion
Northern Gulf		31 XII '95	765-596	Teredo
		14 I '96	19-50	Chafe
		12 X '96	334-293	Corrosion
	20 X '96	14 XI '96	23	Chafe
	1 X '97	3 X '97	32	Chafe
	25 IX '97	2 X '97	18	Chafe
		18 VII '98		Fault at kink
	30 V '99	2 VI '99		Chafe
	27 VI '99	30 IX '99	75-110	Chafe and corrosion
		20 VIII '99	320-294	Teredo
		9 IX '00	45	Fault-no data
		18 X '00		Chafe and corrosion
		31 XII '00		Fault-no data
	[illegible] XII '00	28 XII '00		Chafe

Table A.7 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathoms)	Cause of Failure
Northern Gulf	24 I '03	14 II '03		Chafe
	8 VII '03	13 VII '03		Fault-no data
	5 VIII '03	7 VIII '03		Fault-no data
	31 VII '03	5 VIII '03		Perished core
		22 X '04		Fault-no data
		28 X '04		Fault-no data
		4 XI '04		Fault-no data
Str. of Gibraltar		14 XII '04		Perished core
Northern Gulf		25 VIII '05	300-280	Teredo
		18 III '06		Fault at kink
		19 IX '06		Fault-no data
Str. of Gibraltar	31 XII '06	20 I '07		Corrosion
Northern Gulf	13 I '07	2 II '07		Corrosion
	27 VIII '07	2 IX '07		Break-unrecovered
	15 III '07	24 III '07		Corrosion
Str. of Gibraltar		16 IX '07	138-65	Fault at kink
	7 II '08	9 II '08		Break at surfline during gale
	28 V '08	30 V '08		Chafe and corrosion
	28 V '08	29 V '08		Corrosion
Northern Gulf	2 IX '08	30 X '08	484-384	Perished core
	27 XI '09	30 XI '09		Chafe
		18 V '10		Fault-no data
	22 XII '10	12 I '11		Fault-no data
		14 VIII '11		Fault-no data
Cape St. Vinc	9 VIII '13	12 IX '13	405-429	Fault-no data
Northern Gulf	12 IX '13	15 IX '13	435-430	Fault-no data
	3 III '14	19 III '14		Chafe and corrosion
Cape St. Vinc	23 II '14	10 IV '14	295-276	Many kinks and broken wires
Str. of Gibraltar	30 V '14	2 VI '14	28-19	Chafe
Cape St. Vinc	21 III '15	25 III '15	340-239	Chafe
Northern Gulf	24 III '15	2 V '15	331-314	Serving rotten and mostly fell off-the wires were brittle
	2 V '15	4 V '15	388-402	Wires were brittle and broken on drum continuously
	12 I '16	17 I '16	401-41[illegible]	Cable in bad condition

Table A.7 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
Str. of Gibraltar	25 III '16	26 III '16	49	Badly corroded
	15 VII '16	27 VII '16	53-60	Chafe and corrosion
	20 VIII '16	26 VIII '16	52-54	Fault-not recovered
Northern Gulf	22 V '16	23 VIII '16	410-409	Corrosion
	18 VIII '16	20 VIII '16	486-710	Fault-grapnels hooked in some very stiff clay
Str. of Gibraltar	7 III '17	9 III '17	34-24	Anchor
	3 III '17	13 III '17	55-29	Chafe
	12 III '17	14 III '17	35	Chafe
	18 IV '17	24 V '17	24-21	Anchor
Northern Gulf	3 III '17	23 VII '17	744-343	Cable in bad condition
Str. of Gibraltar	23 II '18	30 V '18	72-38	Cable in very poor condition
	8 VII '18	17 VII '18	53-65	Cable in very poor condition
Cape St. Vinc	23 VII '18	3 IX '18	240-450	Kink and corrosion
Str. of Gibraltar	23 IX '19	6 III '19	22-19	Chafe and corrosion
Northern Gulf		24 V '19	410-458	Fault-no data
Str. of Gibraltar	3 III '20	22 III '20	21-25	Chafe
	21 III '20	26 III '20	24-34	Chafe
	5 V '20	13 V '20		Corrosion
Northern Gulf		21 I '21	705-597	Corrosion at kink
Str. of Gibraltar	31 VIII '21	2 IX '21		Chafe and corrosion
	29 XI '21	4 XII '21	67-150	Break-not recovered
		9 V '23	11-24	Chafe
Cape St. Vinc		15 XII '23	309-288	Trawler
	10 XII '23	3 I '24		Corroded ends
		30 V '25		Fault-not recovered
Northern Gulf	6 V '25	6 V '25	330-340	Trawler
	13 V '25	16 V '25	328-300	Trawler
	28 V '25	29 V '25	115-135	Break-cable was in fair condition except near the break
	21 III '27	30 III '27	428-520	Chafe
	21 III '27	31 III '27	600-1070	Fault-no data
Str. of Gibraltar		XI '27	20-18	Chafe
Northern Gulf	10 II '30	18 II '30	274-493	Corrosion
Str. of Gibraltar	23 IV '30	1 V '30	42-17	Corrosion

Table A.7 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
Northern Gulf	31 VII '30	5 VIII '30	438-474	Badly corroded
Cape St. Vinc	30 XI '31	12 XII '31	382-408	Trawler
Northern Gulf	30 VII '32	21 VIII '32	1070-647	Chafe
Str. of Gibraltar	21 VIII '33	7 IX '33	44-32	Chafe and corrosion
	27 II '34	22 III '34	64-102	Corrosion
Northern Gulf	16 IV '34	23 IV '34	462-415	Perished core at butt of splice
	13 VII '35	6 VIII '35	400-464	Submarine landslide
	16 XII '35	1 II '36	500-920	Corrosion
Str. of Gibraltar	27 I '36	5 II '36	24-37	Corrosion
Northern Gulf	27 VII '36	2 VIII '36	360-515	Chafe
	14 XI '36	2 XII '36	460-360	Corrosion
	3 XII '38	30 XII '38	458-350	Chafe
Cape St. Vinc	1 VI '39	6 VI '39	355-308	Trawler
Northern Gulf	15 XI '39	25 XI '39	450-450	Chafe
	26 IV '40	22 V '40	311-545	Chafe
	14 V '40	29 V '40	452-350	Corrosion
	4 III '41	19 III '41	453-445	Corrosion
	25 III '42	30 IV '42		Chafe
	27 V '42	12 VI '42	497-473	Chafe
	26 [illegible] '43	8 IV '43	410-510	Chafe
		VIII '43	476-500	Corrosion
		17 X '43		Chafe
	13 XI '43	20 IV '44	600-267	Heavy corrosion
	20 XI '44	6 XII '44	605-267	Fault-unrecovered
Str. of Gibraltar	13 VIII '46	18 VIII '46	19-19	Corrosion
	16 VIII '46	17 VIII '46	39-30	Corrosion
	27 I '48	31 I '48	18-17	Severe corrosion
Cape St. Vinc	30 IV '48	23 V '48	355-315	Chafe and corrosion
Northern Gulf	6 VII '48	23 VII '48	530-515	Severe chafe
		15 IX '48	440-410	Teredo
Str. of Gibraltar		5 VII '49		Chafe
	27 VII '49	1 VIII '49		Chafe and corrosion
Northern Gulf	29 IX '49	12 XI '49	540-550	Chafe
Str. of Gibraltar	[illegible] IX '49	9 X '49	16-15	Corrosion
Northern Gulf	5 XII '50	12 XII '50	491-480	Fault-unrecovered
	13 IV '51	26 IV '51	455-512	Chafe
	11 VII '52	21 VII '52	220-350	Chafe
	29 VII '52	[illegible] VIII '52	570-500	Chafe
	31 V '54	20 VII '54	410-480	Break-unrecovered

Table A.7 (Continued)

Location	Date of Failure	Date of Repair	Water Depth @ Splices (Fathom)	Cause of Failure
Northern Gulf	6 II '55	15 III '55	468-478	Chafe and corrosion
Str. of Gibraltar	21 VII '55	25 VII '55	40-31	Chafe and corrosion
Northern Gulf	15 II '56	5 III '56	550-585	Fault-unrecovered
	21 VI '56	30 VI '56	420-500	Severe chafe
	17 IX '57	21 IX '57	288-160	Marine growth and corrosion
	7 XI '57	18 XI '57	230-570	Chafe and corrosion
	22 V '58	31 V '58	450-459	Chafe
Str. of Gibraltar	25 V '58	16 VIII '58	23-43	Chafe
Northern Gulf	26 IX '58	3 X '58	400-510	Chafe
	15 V '59	22 V '59	427-585	Fault-unrecovered
Str. of Gibraltar	18 XII '59	28 XII '59		Chafe
Northern Gulf	30 IV '60	27 V '60	477	Chafe
	14 VII '60	31 VII '60	494-475	Fault-unrecovered
	28 XI '60	3 I '61	575-535	Chafe
	10 V '61	13 V '61	511-524	Chafe
	26 VII '61	13 VIII '61	345-	Fault at twist
Str. of Gibraltar	1 IX '61	8 IX '61		Break-unrecovered
Northern Gulf	1 III '62	6 III '62	473-444	Break-unrecovered
Cape St. Vinc	2 V '62	20 V '62	350-402	Trawler
Northern Gulf	16 XI '62	6 XII '62	458-463	Break-unrecovered
	7 III '63	25 III '63	420-520	Badly chafed
Str. of Gibraltar	8 V '63	11 V '63	67-68	Chafe and corrosion
Northern Gulf	18 X '63	26 X '63	558-509	Severe chafe
Str. of Gibraltar	12 XI '63	18 XI '63	50	Severe chafe
Northern Gulf	9 I '64	13 I '64	350-535	Badly chafed

Table A.8 Gulf of Cadiz Region (Carcavelos-Gibraltar 2) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
South of Tarifa	4 XI '98	8 XI '98		Chafe
	1 VIII '03	3 VIII '03		Fault-no data
Str. of Gibraltar	VIII '04	8 VIII '04		Fault - no data
Northern Gulf	5 V '08	9 V '08	350-330	Teredo
Str. of Gibraltar	8 XI '08	16 I '09	41	Fault-no data
	22 XII '09	9 I '10		Chafe & corrosion
	26 XII '12	29 XII '12	35-25	Corrosion
	28 I '13	13 II '13	20-29	Fault- no data
Northern Gulf	12 II '13	1 III '13	230-135	Fault-cable in fair condition
	23 X '14	25 X '14	64-74	Corrosion
Cape St. Vinc	19 V '15	24 VI '15	64-100	Perished core
Str. of Gibraltar	24 VIII '15	25 VIII '15	28-40	Chafe & corrosion
	28 I '17	2 V '17	18-17	Chafe
Northern Gulf	26 I '17	4 VII '17	64-58	Fault-no data
Str. of Gibraltar	15 I '18	29 IV '18	16-31	Chafe & corrosion
	8 IX '18	9 IX '18	35	Chafe & corrosion
Cape St. Vinc	24 IX '18	30 IX '18	180-62	Chafe & corrosion
Northern Gulf	15 XI '18	19 XII '18	335-325	Fault-unknown
		22 V '19	325	Fault-no data
Str. of Gibraltar	4 I '20	20 I '20		Chafe
Northern Gulf	25 IX '20	11 X '20	325	Perished core
Str. of Gibraltar	11 IV '22	13 IV '22		Chafe & corrosion
	9 IV '23	4 V '23	61-60	Trawler
	16 XI '22	21 XI '22	58-51	Trawler
		30 XI '22	57-330	Trawler
		1 XII '22	92	Trawler
	20 V '23	27 V '23	45	Fault-not recovered
	23 XII '23	5 I '24	60-40	Fault-not recovered
	1 IV '24	10 IV '24	42-25	Corrosion
Northern Gulf		18 VI '25	327-327	Trawler
	12 VI '25	17 VI '25		Trawler
	19 VI '25	21 VI '25	327-327	Trawler
	13 VII '25	16 VII '25	325-330	Trawler
Str. of Gibraltar		5 II '26	16-21	Chafe
		14 II '28	[illegible]	Chafe & corrosion
		19 XII '28	[illegible]	Anchor
Northern Gulf		18 VII '2[illegible]	[illegible]	Corroded kink

Table A.8 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar		3 V '30	20-23	Chafe & corrosion
Northern Gulf		13 XII '30	39-23	Trawler
		16 IX '31	43	Trawler
		26 XI '31	54-55	Anchor
Str. of Gibraltar		9 III '32	13	Break-not recovered
		14 V '32		Anchor
Northern Gulf		29 X '32	50-53	Break at kink
Str. of Gibraltar		28 III '33	15	Chafe & corrosion
		8 I '34	13-20	Fault-not recovered
Northern Gulf		25 III '34	42-44	Fault at kink
Str. of Gibraltar		28 VI '34	16-17	Corrosion
		3 III '35	12-19	Break-not recovered
Northern Gulf		8 IX '35	23-29	Chafe & corrosion
Str. of Gibraltar		28 IV '36	16-19	Corrosion
		30 IV '36	10-23	Corrosion
Northern Gulf		14 VIII '36	60-75	Chafe
Str. of Gibraltar		7 X '36	13-206	Chafe
		6 XII '36	16	Corrosion
		8 III '37	18	Break-not recovered
Northern Gulf		4 VI '38	39-40	Trawler
		21 V '39	25-27	Chafe & corrosion
		29 IX '39	28-31	Break-unrecovered
		15 VIII '40	15-16	Trawler
Str. of Gibraltar		26 II '41	15-20	Break-unrecovered
		28 II '41	16-19	Corrosion and anchor
		6 V '41	10-14	Chafe
Northern Gulf		1 X '41	100-265	Perished core
		3 X '41	44-50	Corrosion
Str. of Gibraltar		20 X '43	15	Chafe
		13 XI '43	46-125	Corrosion
Northern Gulf		9 VI '44	25-26	Chafe & corrosion
		29 XI '44	29-32	Corrosion
Str. of Gibraltar		27 XII '45	16-26	Corrosion & trawler
		12 I '46	23-46	Chafe & corrosion
Northern Gulf		25 I '46	40-4[illegible]	Saw cut
		11 VIII '46	2[illegible]	Corrosion
		16 IX '46	30	Chafe
		1[illegible] II '47	[illegible]	Chafe & corrosion
		1 IX '47	3[illegible]	Trawler
Str. of Gibraltar		[illegible] X '47	40-4[illegible]	Corrosion
Northern Gulf		23 XII '47	4[illegible]-50	Fault at kink

Table A.8 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar		30 III '48	10-26	Chafe & corrosion
		28 VII '48	15	Corrosion
Northern Gulf		16 VIII '48	40	Corrosion
Str. of Gibraltar		19 VIII '48	22	Corrosion and tension
		16 I '50	19-23	Chafe & corrosion
		18 I '50	17-19	Fault-unrecovered
Northern Gulf		19 I '50	82-117	Trawler
		22 IV '50	23-30	Break-unrecovered
Str. of Gibraltar		9 XII '50	13-15	Break-unrecovered
Northern Gulf		13 XII '50	32	Trawler
Str. of Gibraltar		20 XI '51		Corrosion
Northern Gulf		1 II '52	50	Corrosion
		2 II '52	51	Corrosion
		17 IX '52	42	Corrosion
		22 VI '53	25	Trawler
Cape St. Vinc		14 XII '53	30-38	Trawler
Str. of Gibraltar		8 IV '54	15-31	Fault-unrecovered
Northern Gulf		11 IV '54	17-20	Fault-unrecovered
		9 V '54	25	Break-unrecovered
Str. of Gibraltar		13 VII '54	14	Chafe & corrosion
Northern Gulf		11 VIII '54	28	tension & corrosion
		21 X '54	44	Corrosion
		15 VII '55	51	Trawler
		23 XI '55	31	Break-unknown
Str. of Gibraltar		27 II '56	12-16	Chafe & corrosion
Northern Gulf		15 VIII '56	52	Trawler
		1 V '57	40	Break-unknown
		7 VIII '57	48	Chafe & corrosion
Str. of Gibraltar		3 II '58	21	Corrosion
		16 V '58	24	Fault-unknown
Northern Gulf		23 VII '58	44	Break-unrecovered
		27 VII '58	50	Trawler
		4 XI '58	37	Trawler
Str. of Gibraltar		27 XII '58	16	Chafe & corrosion
		28 XII '58	26	Corrosion
Northern Gulf		29 XII '58	70	Corrosion
Cape St. Vinc		28 IV '59	33-35	Tension
Str. of Gibraltar		4 VII '59	21-20	Break-unrecovered
Northern Gulf		28 VII '59	36-30	Trawler
		10 VIII '59	25-27	Trawler

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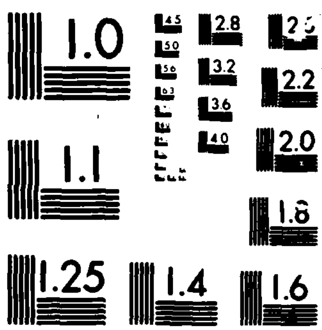

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Table A.8 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Northern Gulf		1 X '59	42-41	Trawler
		17 XII '59	63-52	Corrosion
Str. of Gibraltar		3 V '60	16-55	Break-unrecovered
		16 VII '60	26-25	Corrosion
		14 IX '60	25-41	Chafe & corrosion
Northern Gulf		7 X '60	50-50	Trawler
		18 X '60	39-37	Trawler
Cape St. Vinc		23 XII '60	26-26	Break-not recovered
		25 IV '61	28-24	Trawler
Northern Gulf		25 V '61	50-48	Trawler
Cape St. Vinc		11 VI '61	35-37	Trawler
Str. of Gibraltar		9 XII '61	15	Chafe & corrosion
		25 I '62	22-21	Trawler
Northern Gulf		21 VII '62	262-355	Trawler
		26 IX '62	57-59	Corrosion
		1 I '63	260-330	Trawler

Table A.9 Gulf of Cadiz Region (Carcavelos-Gibraltar 4) Submarine Cables (Ref. 8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar	12 VII '48	24 VIII '48	55-46	Corrosion
Northern Gulf	9 III '49	18 III '49	358-248	Corrosion
Cape St. Vinc	11 V '49	21 V '49	275-278	Trawler
	29 IX '49	8 X '49	280-285	Trawler
Northern Gulf	20 VIII '50	4 VIII '50	245-300	Corrosion
	15 VI '51	24 VI '51	315-298	Chafe
	27 VIII '51	31 VIII '51	298-333	Cut by axe
Str. of Gibraltar	16 X '51	19 X '51		Anchor
Cape St. Vinc	25 I '52	3 II '52	92-184	Chafe & corrosion
Str. of Gibraltar	29 I '52	8 II '52		Chafe & corrosion
Northern Gulf	3 IV '52	17 V '52	302-305	Corrosion
	23 V '52	31 V '52	310-310	Corrosion
Cape St. Vinc	10 IX '52	15 IX '52	278-275	Trawler
Northern Gulf	15 III '53	21 III '53	252-255	Perished core
Str. of Gibraltar	11 VIII '53	14 VIII '53	130-85	Chafe
Cape St. Vinc	19 IX '53	28 IX '53	280-295	Trawler
Northern Gulf	26 X '53	21 XI '53	250-225	Trawler
Str, of Gibraltar	24 X '53	24 XI '53	39-117	Chafe & corrosion
Northern Gulf	17 II '54	19 II '54	161-141	Trawler
Str. of Gibraltar	25 III '54	30 III '54	26-39	Break-unrecovered
Northern Gulf	30 III '54	21 IV '54	340-290	Perished core
Str. of Gibraltar	17 II '55	16 III '55	40-25	Chafe & corrosion
	15 I '55	19 III '55	26-26	Chafe
Cape of St. Vinc	9 X '55	10 X '55	335-76	Corrosion
Northern Gulf	24 I '57	2 II '57	165-148	Trawler
Str. of Gibraltar	1 II '57	3 II '57	31-68	Corrosion
Northern Gulf	22 VII '57	8 VIII '57	280-300	Corrosion
	12 XII '57	16 XII '57	225-185	Corrosion
Str. of Gibraltar	16 XII '57	19 XII '57	36-42	Chafe
Northern Gulf	17 XII '57	17 I '58	277-313	Trawler
Str. of Gibraltar	31 V '58	1 VI '58	47-32	Corrosion
Northern Gulf	27 V '58	18 VI '58	154-263	Trawler
Str. of Gibraltar	20 XII '58	24 XII '58	42-27	Chafe & corrosion
Northern Gulf	27 IV '59	29 IV '59	430-343	Fault-unrecovered
	4 V '59	12 V '59	68-156	Trawler
Str. of Gibraltar	17 VI '59	20 VI '59	28-[illegible]	Chafe & corrosion
	21 VII '59	24 VII '59	61-108	Chafe
Northern Gulf	1 VIII '59	13 VIII '59	260-300	Trawler
	15 XI '59	27 XI '59	111-120	Trawler
	23 IV '60	2[illegible] IV '60	189-1[illegible]8	Corrosion

Table A.9 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar	10 IX '60	15 IX '60	44-92	Chafe
	3 I '61	4 I '61	43-39	Trawler
	19 I '61	1 II '61	38-28	Chafe
	23 XII '61	4 I '61	14-14	Severe chafe
	9 III '62	13 III '62	19-19	Chafe
Cape of St. Vinc	30 IV '62	2 V '62	319-295	Trawler
Northern Gulf	20 IX '62	27 IX '62	425-328	Chafe
Str. of Gibraltar	10 XI '62	5 XII '62	30-31	Cable ragged
Northern Gulf	12 VI '63	12 VI '63	175-137	Trawler
Str. of Gibraltar	26 VIII '63	6 IX '63	44-41	Break-unrecovered
Northern Gulf	16 IX '63	18 IX '63	318-283	Trawler
Str. of Gibraltar	19 XII '63	21 XII '63	12-25	Fault-unrecovered

Table A.10 Gulf of Cadiz Region (Gibraltar-Casablanca) Submarine Cables (Ref. 8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar		31 X '43		Chafe
West off	24 III '44	21 IV '44	200-250	Chafe
Gibraltar	20 IV '44	30 IV '44	290-244	Chafe
	21 VII '44	17 X '44	200-250	Chafe
Str. of Gibraltar	29 X '44	5 XI '44	150-135	Break-unrecovered
	5 XI '44	10 XI '44	77-93	Core spew
		24 V '45	210-200	Break-unknown
	25 VIII '45	17 IX '45	54	Fault-all cable in very bad condition and can not be used again
	21 XII '45			Cable abandoned

Table A.11 Gulf of Cadiz Region (Porthcurno-Gibraltar 3) Submarine Cables (Ref. 8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Northern Gulf	8 I '07	12 I '07		Trawler
	23 I '08	26 I '08	18-20	Chafe
Str. of Gibraltar	2 II '12	2 II '12	15-15	Chafe
Northern Gulf	5 III '12	12 III '12	27-19	Trawler
	16 X '13	18 X '13	39-42	Trawler
Str. of Gibraltar	16 III '16	18 III '16	14-23	Anchor
	24 II '16	3 III '16		Anchor
	11 III '16	23 III	17-19	Chafe & corrosion
	18 XI '16	20 XI '16		Anchor
	17 XII '16	22 XII '16	12-14	Chafe
	16 III '17	21 III '17		Anchor
	22 X '17	29 X '17	15-17	Chafe
Northern Gulf	31 V '18	8 VI '18	20-17	Break-tuna net anchor at corroded place
	21 VIII '18	25 VIII '18	31-175	Anchor
	14 III '19	18 III '19	40-39	Anchor
	20 III '19	26 III '19	25-20	Anchor
	28 IV '20	29 IV '20	48-40	Anchor
	8 X '21	9 X '21	24-23	Trawler
Cape St. Vinc	26 I '22	9 II '22	108-51	Chafe & corrosion
Northern Gulf	7 VII '23	9 VII '23	46-46	Trawler
	23 XII '23	31 XII '23	35-40	Trawler
	31 XII '23	1 I '24	25-26	Trawler
Str. of Gibraltar	16 I '24	24 I '24	176-14	Fault-not recovered
Northern Gulf	28 III '24	8 IV '24	23	Trawler
Gibraltar	12 IV '27	15 IV '27		Break-cable crushed by rocks
	15 VIII '27	19 VIII '27	42	Corrosion
		29 III '28		Anchor
	30 VI '30	8 VIII '30	335-220	Fault-not recovered
	19 II '32	26 II '32		Chafe & corrosion
	25 II '32	6 III '32	19	Break-not recovered
	23 V '32	30 V '32	57-56	Chafe & corrosion
		27 VI '32	95-40	Chafe
		24 VI '32	55-43	Chafe
	29 X '32	31 X '32	45-20	Chafe
	6 XII '34	21 XII '34	3[illegible]-86	Break-not recovered
	21 IV '36	29 IV '36	100-17	Corrosion
	8 VIII '37	16 VIII '37	32[illegible]-215	Heavy corrosion
	13 X '37	18 X '37		Anchor

Table A.11 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Gibraltar	20 III '38	22 III '38	30-88	Break-no data
	3 V '39	8 V '39	319-249	Chafe
	16 I '41	24 II '41	67-59	Corrosion
	12 IV '41	3 V '41		Break-at water's edge during a gale
Northern Gulf	22 I '43	24 II '43	500-509	Corrosion
	18 IX '44	16 X '44	510-500	Fault-unknown
Str. of Gibraltar	9 I '44	19 IX '44	22-10	Corrosion
	10 VII '45	18 VII '45	40-32	Chafe
	4 I '46	10 I '46	16-18	Chafe
Northern Gulf	18 VI '46	26 VI '46	520-500	Chafe & corrosion
	26 IV '47	6 IV '47	950-875	Corrosion
	11 VIII '47	15 VIII '47	250-200	Chafe & corrosion
	10 XI '47	26 XI '47	540-500	Chafe & corrosion
Str. of Gibraltar	1 I '48	4 I '48	77-85	Chafe & corrosion
	7 VIII '48	12 VIII '48	295-230	Chafe
	4 IV '49	25 IV '49	326-247	Chafe
	28 IV '49	4 V '49	38-41	Chafe
		30 VIII '49	59-73	Renewal-cable in good condition, but chafe and corrosion in several parts
	16 XII '49	17 XII '49	21-21	Corrosion
	12 XII '49	15 XII '49	21-21	Break-unrecovered
Northern Gulf	23 XII '49	12 I '50	432-350	Severe chafe & corrosion
	20 V '50	30 V '50	502-500	Chafe
Str. of Gibraltar	22 VI '52	4 VII '52	58	Break-unrecovered
Northern Gulf	19 III '54	28 III '54	634-524	Fault-cable mostly bare and bad corrosion
	2 V '55	6 V '55	1020-1170	Corrosion
Str. of Gibraltar	19 V '55	28 V '55	40-44	Extreme chafe
	8 IX '56	10 IX '56	37-46	Severe chafe
Northern Gulf	22 XII '57	30 XII '57	525-505	Severe chafe
Str. of Gibraltar	29 X '59	5 XII '59	63-206	Chafe
Northern Gulf	18 VII '60	20 VII '60	867-634	Heavily corroded

Table A.12 Gulf of Cadiz Region (Porthcurno-Gibraltar 4) Submarine Cables (Ref. 8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar	9 VI '20	26 VI '20	109-171	Chafe
	10 X '20	13 X '20		Chafe
Cape St. Vinc	24 XI '23	2 XII '23	209-212	Trawler
	15 I '24	19 I '24	217-200	Trawler
	11 XI '24	15 XI '24	235-250	Trawler
Northern Gulf	3 V '25	6 VI '25	340-335	Trawler
	17 VIII '25	19 VIII '25	345-346	Trawler
Str. of Gibraltar	19 III '27	25 III '27	121	Chafe & corrosion
	30 VII '28	15 VIII '28	130-165	Chafe
Northern Gulf	11 VII '29	28 VII '29	602-555	Chafe
Str. of Gibraltar	18 VI '31	3 VII '31	190-170	Chafe & corrosion
Northern Gulf	8 II '33	15 II '33	370-310	Chafe
	28 VIII '33	20 IX '33	655-590	Chafe & corrosion
Str. of Gibraltar	15 V '34	21 VI '34	173-173	Corrosion
	15 VIII '34	21 VIII '34	210-175	Break-cable ragged and bare, some chafe
	28 X '34	1 XI '34	197-175	Fault-not recovered
	3 IV '35	13 V '35	216-252	Chafe
	10 VII '36	11 VII '36	110-95	Chafe & corrosion
	30 I '37	2 II '37	133-49	Corrosion
Northern Gulf	25 III '37	1 IV '37	667-556	Corrosion
Str. of Gibraltar	13 IV '37	27 IV '37	43-45	Chafe & corrosion
	28 XI '37	13 XII '37	124	Break-unrecovered
	30 VI '38	7 VII '38	45-52	Chafe & corrosion
Northern Gulf	31 VIII '39	1 X '39	712-627	Chafe & corrosion
	23 XII '39	29 XII '39	341-397	Chafe
Str. of Gibraltar	27 I '40	30 I '40	210-130	Corrosion
Northern Gulf	16 VII '41	17 VII '41	670-652	Corrosion
	9 VI '47	6 VII '47	652-580	Break-cable broke at repaired splice
Str. of Gibraltar	1[illegible] XII '47	17 XII '47	80-180	Chafe & corrosion
Northern Gulf	1 V '48	15 V '48	576-545	Fault-corroded twist
	13 II '49	19 II '49	510-555	Corrosion
	[illegible] IV '49	30 IV '49	345-340	Break-hooked by ship
Str. of Gibraltar	31 VII '49	3 VIII '49	165-175	Chafe
Northern Gulf	[illegible] X '50	1 XII '50	608-610	Chafe
Str. of Gibraltar	[illegible] '51	29 [illegible] '51	160-145	Heavily chafed and corroded
Northern Gulf	3 V '51	[illegible] VII '51	43[illegible]-333	Chafe
Gibraltar	[illegible] '52	[illegible] '52	40-200	Chafe

Table A.12 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathoms)	Cause of Failure
Gibraltar	25 II '52	5 III '52	149-190	Break-unrecovered
	23 XII '53	28 XII '53	100-190	Chafe & corrosion
	19 XII '55	28 XII '55	110	Fault-crushed cable
	13 II '56	3 III '56	150-140	Severed chafe
Northern Gulf	17 XI '56	2 XII '56	320-250	Severe chafe
	16 III '57	25 III '57	360-340	Chafe
Str. of Gibraltar	23 II '59	1 III '59	163-154	Chafe
	20 IV '59	5 V '59	123-149	Severe chafe
	19 II '60	1 III '60	115-91	Severe chafe
	15 III '63	28 III '63	124-237	Break-unrecovered
	10 V '63	11 V '63	121-237	Chafe
	1 XII '63	9 XII '63	112-208	Chafe

Table A.13 Gulf of Cadiz Region (Vigo-Gibraltar) Submarine Cables (Ref. 8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar	25 IV '02	1 V '02		Chafe
		8 XII '04		Chafe
	19 VIII '07	30 VIII '07		Chafe & corrosion
	2 II '12	15 II '12		Break-not recovered
	28 V '15	30 V '15		Chafe
	19 I '16	24 I '16	22-15	Chafe
	22 IV '16	1 VI '16	73-100	Corrosion
	5 V '16	20 V '16	67-51	Chafe & corrosion
	20 XI '16	24 XI '16	35-18	Corrosion
	17 XII '16	9 II '17	19-22	Chafe & corrosion
	22 I '18	6 II '18	14-13	Chafe & corrosion
	25 VI '18	8 IX '18	66-32	Chafe & corrosion
	3 X '18	17 XI '18		Anchor
Northern Gulf	11 V '20	15 V '20		Trawler
Str. of Gibraltar	13 X '20	14 X '20	70-48	Chafe & corrosion
	20 III '22	24 III '22	15-16	Chafe
Northern Gulf	14 IX '22	27 X '22		Trawler
	14 III '23	15 III '23	58-58	Trawler
	28 II '23	6 III '23	51-54	Trawler
		2 IV '23	44-47	Break-unknown
		5 X '23	42-40	Corrosion
Str. of Gibraltar	3 VII '24	6 VII '24	100-103	Chafe & corrosion
Northern Gulf	10 XII '23	14 XII '23	116-123	Fault at kink
Str. of Gibraltar	14 III '25	21 III '25	28-56	Fault-not recovered
Northern Gulf	20 V '25	27 V '25	152-149	Trawler
	28 VI '25	30 VI '25	61-57	Trawler
Cape St. Vinc	18 III '25	2 VII '25	373-335	Fault-unknown
	14 I '26	15 I '26	340-75	Chafe & corrosion
Str. of Gibraltar		8 V '26	29-38	Chafe & corrosion
Northern Gulf		20 VI '26	116-124	Trawler
Str. of Gibraltar		3 III '27	20	Chafe & corrosion
		7 III '27	15-30	Chafe & corrosion
		18 IV '27		Break at water edge
		18 IV '27	37-208	Chafe
		26 XI '27	[illegible]	Chafe
		26 XI '27	19-17	Chafe
Northern Gulf		14 V '28	42-44	Trawler
		1 VI '28	15	Trawler
		4 X '28	52	Trawler
		[illegible] I '30	53	Break-not recovered

Table A.13 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Gibraltar		11 I '30	75-127	Fault at kink
Cape St. Vinc		5 II '30	63-77	Break due to strain
Str. of Gibraltar		7 V '30	15-18	Corrosion
		17 VIII '30	75-104	Break-not recovered
Northern Gulf		9 IX '30	137-143	Trawler
Cape St. Vinc		1 XI '30	105-300	Chafe & corrosion
Northern Gulf		12 XII '30	18-88	Chafe
		19 IV '31	147-168	Trawler
Str. of Gibraltar		21 IV '31	11-18	Chafe & corrosion
Northern Gulf		27 VI '31	133-140	Trawler
Str. of Gibraltar		28 XI '31	23-25	Corrosion
		30 XII '32	25-31	Chafe & corrosion
Northern Gulf		2 I '33	32-40	Trawler
		17 XI '34	150-153	Corrosion
Str. Gibraltar		2 V '35	92-97	Chafe
Northern Gulf		15 IX '35	134-165	Break-cut by axe
Cape St. Vinc		17 IX '35	73-308	Trawler
Northern Gulf		5 XII '36	16-18	Corrosion
Gibraltar		13 XII '36	42-115	Break-unrecovered
		5 II '37	18-23	Corrosion
Northern Gulf		10 X '37	48-53	Trawler
Gibraltar		18 XII '37	32-37	Corrosion
		20 XII '37	54-100	Corrosion
		13 II '38	11-15	Corrosion
Northern Gulf		14 II '38	33-42	Chafe & corrosion
		6 VII '38	125-152	Trawler
Str. of Gibraltar		12 VII '38	42-44	Fault-unknown
		30 X '38	26-50	Chafe & corrosion
Northern Gulf		5 VIII '39	36-38	Chafe & corrosion
Str. of Gibraltar		19 X '39	29-39	Anchor
		12 I '40	35-93	Chafe
Northern Gulf		20 V '40	163-175	Trawler
Cape St. Vinc		1 XI '40	329-352	Trawler
		2 XI '40	32-40	Fault-unknown
Str. of Gibraltar		27 I '41	20-23	Corrosion
		28 [illegible] '41	20-23	Corrosion
		23 II '41	15-16	Corrosion
Northern Gulf		30 V '47	24-29	Corrosion
		30 V '47	51	Chisel cut
		31 V '47	[illegible]	Axe cut

Table A.13 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Northern Gulf		4 VI '47	145-160	Axe cut
		3 VI '47	110-118	Trawler
		5 VI '47	56	Chafe
		6 VI '47	43	Break-unrecovered
		7 VI '47	48-54	Corrosion
		7 VII '47	100-145	Saw cut
		24 VII '47	135-140	Trawler
		12 VII '47	55-60	Break-unrecovered
		11 I '49	53-110	Corrosion
Cape St. Vinc		21 II '49	48-62	Axe cut
		2 IV '49	240-328	Trawler
		23 V '49	350	Trawler
		7 VII '49	125-328	Saw cut
Str. of Gibraltar		6 X '49	24	Chafe
Northern Gulf		14 XI '49	36-45	Saw cut
		11 III '50	165	Trawler
		28 VI '50	45-49	Trawler
Cape St. Vinc		29 VI '50	300-302	Trawler
Northern Gulf		2 XII '50	49	Saw cut
		6 II '51	34-57	Fault at kink
		7 X '51	43	Corrosion
		15 V '52	18	Tension at break
		19 V '52	155-172	Trawler
		11 XII '52	54	Break-unrecovered
		30 I '53	18-24	Trawler
		15 II '53		Trawler
		20 XI '53	165	Trawler
		8 V '54	53	Corrosion
		17 VII '54	61-120	Break-unrecovered
		26 XI '54	158	Trawler
Str. of Gibraltar		20 XII '54	113	Break-unrecovered
Northern Gulf		14 VII '55	145	Trawler
		17 VIII '55	20	Trawler
		22 XII '55	15-20	Trawler
Str. of Gibraltar		21 [illegible] '56	100-110	Chafe
		'56		Cable abandoned

Table A.14 Gulf of Cadiz Region (Horta-Malaga) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Gibraltar	18 XI '40	18 III '41		Heavy chafe
	4 X '45	12 XII '45	265-310	Chafe
	30 VIII '46	15 IV '46	225-165	Chafe
	6 IV '47	23 IV '47	111-45	Chafe
	6 V '47	18 V '47	319-263	Chafe
	12 I '48	6 II '48		Chafe
	12 I '48	10 II '48	290-96	Severe chafe
		31 VII '48	310-265	Cable in very poor condition, rusty and corroded
		'49		Cable restored, no repair since.

Table A.15 Gulf of Cadiz Region (Las Palmas-Malaga) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Str. of Gibraltar		2 IV '43	220-50	Chafe
	24 XII '45	27 III '46	135-155	Chafe
	23 X '48	1 III '49		Chafe
West off Gibraltar		26 V '50	325-56	Corrosion at kink
		17 XI '50	370-335	Badly chafed
		25 IX '51	373-324	Moderate to severe chafe
		24 XII '51	328-368	Severe chafe
	18 XII '51	14 VI '52	215-277	Chafe
		13 XII '52	380-330	Chafe
		22 III '56	165-170	Chafe
		4 VIII '56	310-300	Chafe
	29 XII '62	11 I '63	135-350	Corrosion
		28 II '63	240-360	Break-outer serving torn and ragged - some polishing of wires after less than 3 days on bottom.

Table A.16 Gulf of Cadiz Region (Lisbon-Malaga) Submarine Cables (Ref.8)

Location	Date of Failure	Date of Repair	Water Depth (Failure)	Cause of Failure
Gibraltar		28 XII '42		Chafe & corrosion
	4 V '46	6 VI '46	155-150	Break-unrecovered
		27 XII '47	14-47	Anchor
	21 II '47	2 IV '48	175-130	Chafe
West of Gibraltar		20 XI '50	230-123	Fault-unrecovered
		4 IX '51	180-240	Chafe
	4 IX '51	7 IX '51	200-182	Break-cable bare, strained and chafe
		27 II '51	175-250	Chafe
		25 IX '52	350-327	Break-wires bare kinks and spews
		28 III '53	357-349	Chafe
		30 XII '55	104-126	Corrosion
		1 XII '56	145-275	Chafe
	12 I '58	16 I '58	306-290	Chafe & corrosion
		24 XI '61	432-382	Severe corrosion

Table A.17 U.S. Air Force Cable Systems*

Location	Date of Failure	Date of Failure	Water Depth (Fathom)	Cause of Failure
South East Asia				
North Coast of Taiwan	5 XII '74	21 XII '74	0	Chafe
	30 VII '76	15 VIII '76	84	Earthquake
	6 IV '77	9 V '77	110	Corrosion
	12 IX '78	9 X '78	16	Ship anchor
	23 V '79	9 VI '79	118	Corrosion
Saitahip, Thailand	4 X '67	13 X '67	14	Ship anchor
	30 XI '72	6 XII '72	12	Ship anchor
	23 VI '73	29 VI '73	19	Ship anchor
	5 XI '73	14 XI '73	12	Ship anchor
	18 II '74	1 III '74	12	Ship anchor
Qui Nhon, Viet Nam	30 VII '68	4 VIII '68	15	Stray shrapnel penetration of cable
	29 IX '70	7 X '70	65	Ship anchor
	10 X '73	20 X '73	0	Malacious damage or subotage
Nha Trang	4 II '69	13 II '69	30	Ship anchor
	18 I '69	21 I '69	0	Excavation
	24 IX '73	30 IX '73	7	Tension damage due to fishing gear or anchor pull
	17 XI '73	23 XI '73	0	Malicious damage on beach at water level
Da Nang	10 IV '69	12 IV '69	0	Excavation
	20 IX '69	28 IX '69	15	Ship anchor
	14 XII '69	19 XII '69	0	Excavation
	14 XI '70	17 XI '70	0	Excavation
	15 XII '74	30 XII '74	0	Malicious damage at waterline level

* Data were obtained through telephone conversation with cable systems maintenaance personnel (Supplied by Mr. J. Martin/FTC-1)

Table A.17 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
Vung Tau,Viet Nam	24 VIII'70	31 VIII'70	30	Ship anchor
	29 XI '71	5 XII '71	19	Ship anchor
	22 XII '71	29 XII '71	17	Trawler
	11 V '72	19 V '72	12	Fishing net damage
	14 VI '72	21 VI '72	20	Cable cut by fisher-man
	4 VIII'72	10 VIII'72	17	Trawler
	15 IV '73	21 IV '73	28	Trawler
	24 XI '73	30 XI '73	28	Trawler
	28 IV '74	4 V '74	28	Trawler
	5 IX '74	21 IX '74	25	Trawler
	11 II '75	15 II '75	27	Trawler

Table A.18 Pacific and Far East Pacific Submarine Cables*

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
CANADA				
Fort Alberni	5 IV '64	12 IV '64	80	Siesmic disturbance and tidal wave
	4 III '71	11 III '71	30	Ship anchor
	1 IV '72	4 IV '72		Tension/abrason
	6 VII '72	15 VII '72	17	Trawler
	27 XII '73	7 I '74	18	Ship anchor
	19 III '74	6 IV '74	17	Insulation fault at old splice
	13 VII '74	27 VII '74		Chafe
	27 VII '74	10 VIII '74	30	Trawler
	14 X '74	28 X '74	50	Trawler
	30 IV '75	18 V '75	15 - 100	Planned cable diversion to avoid trawler fishing area
Vancouver	5 IV '72	8 IV '72	15	Ship anchor
	8 VII '72	19 VII '72	15	Ship anchor
USSR				
Nakhodka	10 XII '72	20 XII '72	100	Abrasion break
JAPAN				
Ninomiya	12 VII '72	17 VII '72	50	Abrasion chafe break
	15 IX '78	21 IX '78	20	Junction box failure
Reihoku	22 I '80	15 III '80	100	Tension break
CHINA				
Nanhui	27 VII '76	1 VIII '76	70	Tension fault
	11 X '78	9 XI '78	100	Tension break
	10 V '80	4 VI '80	120	Tension break
HONG KONG				
Deep Water Bay	18 X '66	24 X '66	15	Cable cut by fishermen
	[illegible] X '70	9 XI '70	120	Tension break due to earthquake

* Data were obtained through telephone conversation with cable systems maintenance personnel (Supplied by Mr. [illegible] Martin [illegible])

Table A.18 (Continued)

Location	Date of Failure	Date of Repair	Water Depth (Fathom)	Cause of Failure
HONG KONG				
Deep Water Bay	20 V '75	28 V '75	40	Trawler
	1 VIII '75	2 VIII '75	30	Ground cable failure
	10 X '76	19 X '76	80	Trawler
	8 XI '76	19 XI '76	70	Torsion-tension break
PHILLIPPINE				
Baler	27 VII '67	4 IX '67	150	Cable tension break
MALAYSIA				
Kota Kinabal	27 V '74	8 VI '74	10	Ship anchor
	26 V '75	3 VI '75	50	Trawler
	14 XII '77	17 XII '77	50	Chafed cable and tension break
SINGAPORE				
	3 VII '71	12 VII '71	17	Trawler
	3 XII '78	10 XII '78	17	Ship anchor
NEW GUINEA				
Madang	7 II '68	18 IV '68	3000	Earthquake
	1 X '68	15 X '68	2200	Earthquake
	20 XI '70	9 XII '70	200	Earthquake
	3 VI '76	18 VI '76	100	Earthquake
	26 IV '77	8 V '77	1800	Earthquake
	13 II '78	3 III '78	50	Earthquake
	25 VI '79	30 VI '79	150	Earthquake
	25 VI '79	7 VII '79	150	Earthquake
AUSTRALIA				
Cairns	15 XI '70	27 XI '70	200 - 1000	Landslide due to earthquake
Sydney	4 I '72	6 I '72	20	Repeater failure

Table A.19 Submarine Power Transmission Cable Failure Record (Ref. 34)

Location	Type of Cable	Water Depth (fm)	Years of Service	No. of Lines	Total No. Faults	Cause of Failure
Vancouver Island B.C.Mainland	Gas	30	23 (1956-79)	5	3	2- Ship anchor 1-others
			21 (1958-79)	2		
Channel France-England	Solid	10	18 (1961-79)	4	29	3-Ship anchor 16-Trawler 5-repair joint 1-lead sheath 4-others (*)
Sweden-Denmark (Kontiskan)	Solid		14 (1964-68)	2	26	12- Trawler 7-repair joint 6-factory joint 1-lead sheath
Denmark (Kontiskan)	Oil		14 (1964-68)	2	8	2- Trawler 6-lead sheath
			9 (1970-79)	1	0	
New Zealand (North-south Isl.)	Gas	42	12 (1965-77)	3	1	1-repair joint
Vancouver Island B.C.Mainland	Solid	32	10 (1969-79)	3	2	2-Ship anchor
	Oil		5 (1974-79)	2	0	
Long Island (Connecticut)	Oil	15	4 (1969-73)	7	10	7- Ship anchor 3-Chafe & corrosion
Skagerak (Norway-Denmark)	Solid	90	4 (1976-80)	1	2	2-Trawler
			3 (1977-80)	1	0	

(*) 2-thermal failure in the land portions of the channel crossing.

Table A.19 (Continued)

Location	Type of Cable	Water Depth (fm)	Years of Service	No. of Lines	Total No. Faults	Cause of Failure
Prince Edward Isl. New Brunswick	Oil	3	2 (1977-79)	6	1	1-others
Norway-Various	Oil		Various	3	2	2-Trawler
Norway-Oslo Fjord	Oil		20 (1959-79)	3	1	1-Trawler
Norway-Oslo Fjord	Oil		4 (1975-79)	6	0	

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